TRANSACTIONS

of the

American Society for Steel Treating

Vol. VII March, 1925 No. 3

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS

SINTON HOTEL, CINCINNATI, OHIO
JANUARY 14, 1925, 10.00 A. M.

Present	*Present*
W. S. BIDLE	F. E. MCCLEARY
R. M. BIRD	F. G. HUGHES
DR. ZAY JEFFRIES	*Absent*
W. H. EISENMAN	DR. G. K. BURGESS
J. F. HARPER	DR. P. D. MERICA

A RESOLUTION appointing Dr. P. D. Merica to fill a vacancy on the Board of Directors for one year was presented and upon motion by Dr. Zay Jeffries, seconded by Mr. Hughes, was adopted.

Upon motion of Mr. McCleary, seconded by Mr. Harper, and unanimously carried, the following resolution was presented and adopted:

> In order to comply with the laws of Ohio in which the directors of the Society elect their own officers, it is hereby resolved that the following officers be elected:
>
> W. S. Bidle, president for one year.
> R. M. Bird, vice president for one year.
> W. H. Eisenman, secretary for two years.
> Dr. Zay Jeffries, treasurer for one year.

The next order of business was the reading and approval of the minutes of the last meeting. Upon motion by Mr. Harper, seconded by Mr. Bird, the minutes were approved.

The following standing committee appointments were recommended and approved by the Board:

Finance Committee: Doctor Zay Jeffries, chairman; Messrs. J. V. Emmons, J. M. Watson, A. G. Henry and A. O. Fulton.

Publication Committee: Professor H. M. Boylston, chairman; Messrs. C. M. Johnson, A. H. d'Arcambal, S. C. Spalding, E. E. Thum, Jerome Strauss, G. C. Lilly, B. F. Shepherd, R. S. Archer, A. W. F. Green, J. L. McCloud, and R. T. Bayless, secretary.

Meetings and Papers Committee: E. C. Smith, chairman; R. T. Bayless, secretary,—members to be appointed later.

Constitution and By-Laws Committee: S. M. Havens, chairman; Messrs. H. J. Stagg, F. H. Franklin, H. K. Briggs, W. P. Woodside, and F. G. Hughes.

Membership Committee: Upon motion by Mr. Bird, seconded by Mr. Hughes, and unanimously carried, the president was authorized to appoint such individuals as he may desire to constitute the membership of this committee.

With reference to the appointment of members on cooperative committees with other societies, a motion properly made, seconded and carried, instructed the secretary to secure reports and information from the A. S. S. T. representatives on these committees of the activity of these committees as well as the advisability of a continuance of the present relationship. The president and secretary were further empowered to determine upon consideration of the reports obtained, whether or not these cooperative committee connections should be continued.

The report of the meeting of the Publication Committee held in Cleveland, November 20, 1924, was then discussed. A number of questions were presented to the Board for ruling, as follows:

1. Relationship of the Meetings and Papers Committee to the Publication Committee.

   The duties of these committees are very closely defined in the Constitution, as follows:

   (a) Meetings and Papers Committee,—it shall be the duty of this committee to secure the presentation of papers and addresses before all sessions of the Society and to aid the local chapters in securing papers and addresses. It will co-operate with the Publication Committee.

   (b) Publication Committee—shall receive all papers and discussions which have been presented at any meeting of the Society or local chapters, and shall recommend what papers and discussions or parts of same shall be printed in the TRANSACTIONS or otherwise given publicity. This committee shall have supervision of the publication of the TRANSACTIONS, and the editor, if one be employed by the National Board, shall be ex-officio member of this committee.

   It was the interpretation of the Board that the Publication Committee has full control of the selection of manuscripts for publication, while

the Meetings and Papers Committee has control of the selection and presentation of papers at conventions and sectional meetings.

A resolution with regard to the preprinting of papers for annual and sectional meetings was next presented.

Upon motion properly made and seconded the Board went on record that it would be the policy for the coming year, to preprint in the regular course of events certain convention papers. The other papers to be presented should provide before their presentation at the convention, a synopsis of the contents, or an extended title. This synopsis to be given general distribution to the members of the Society.

2. To how many reviewers shall a paper be submitted? The suggestion of the Publication Committee that before a paper may be accepted for publication it must receive at least one favorable review by some disinterested person, other than the chairman of the Committee or the editor, but that the total number of reviewers is to be left to the discretion of the chairman,—was approved by the Board.

3. If a paper is approved by a single reviewer, is the Society duty bound to publish said paper, or is this a matter remaining in the hands of the editor? The decision of the Publication Committee,—that the Society shall not be duty bound to publish a given paper which has been reviewed and approved by a single reviewer, and that in case of serious doubt on the part of the editor as to the advisability of publishing a particular paper it shall be submitted to all members of the Publication Committee and the majority vote should decide the matter—was approved by the Board.

4. Upon whom rests the responsibility for the acceptance of Convention papers,—the Meetings and Papers Committe or the Publication Committee?

The Board of Directors went on record as follows:

The Meetings and Papers Committee have complete charge of the selection and presentation of papers for the program of any general meeting of the Society.

The Publication Committee is not bound to accept for publication the papers presented at any general meeting unless such papers are approved and accepted by the Publication Committee.

5. Which of the departments now appearing in TRANSACTIONS are most desirable? How may they be improved? What other departments should be added?

The Board went on record as approving the addition of departments in TRANSACTIONS which would include the practical shop talks, elementary discussions, shop kinks and layouts, and additional material of practical information. The Board further desired to have additional information made available, by adding write-ups of papers given before local chapters. The secretary was instructed to address a letter to the chairman advising them of the desire that more information of chapter activities appear in TRANSACTIONS and to request chapters to send in abstracts of talks presented.

The Board heartily approved the recommendation of the Publication Committe that more practical information on the subject of metallurgy should be made available to the members. Some consideration was given as to the form in which this practical information should be made available to the members,—whether in a separate publication issued at stated intervals, or included in the present publication, TRANSACTIONS.

After considerable discussion it was the opinion of a majority of the Board that the practical subjects should be included in TRANSACTIONS.

6. In the event that a paper be rejected by one member and accepted by another, shall the acceptance or rejection remain in the hands of the editor or chairman? The recommendations of the Publication Committee made in other answers and applying to this question, were approved by the Board.
7. Shall all publications of the Society, including "Data Sheets," come under the jurisdiction of the Publication Committee?
   The Board held that the Publication Committee should determine the papers and discussions to be presented to the Society in TRANSACTIONS, but that the supervision of the printing of data sheets should be under the jurisdiction of the Recommended Practice Committee.
8. Shall the Society publish bibliographies in TRANSACTIONS?
   It was determined that it should not be the policy of the Society to publish bibliographies.
9. Of the temperature scales, which shall be used?
   The recommendation of the Publication Committee that in the editing of manuscripts, the Fahrenheit temperature scale be used, and the equivalent Centigrade figures inserted in brackets,—was approved by the Board.

Appointment of members of the Recommended Practice Committee was next given consideration. After considerable discussion and a review of the activities of the committee it was moved, seconded and unanimously carried that the Recommended Practice Committee should be reduced in size in order to facilitate more frequent meetings.

The following appointments were recommended and approved:

J. F. Harper, chairman; R. M. Bird, R. B. Schenck, W. J. Merten, Dr. J. A. Mathews,—members, and J. E. Donnellan, secretary.

(a) Heat Treating Definitions Sub-committee to be discontinued.
(b) Pyrometry Sub-committee to be discontinued.
(c) Sub-committee on Tool Steel,—as is.
(d) Sub-committee on Plain Carbon and Alloy Spring Steels,—as is.
(e) Sub-committee on Measuring Case Depth,—as is.

An unaudited profit and loss statement for 1924 was presented by Doctor Jeffries, treasurer. This report was accepted and ordered filed.

Consideration was next given to the appointment of a Research Committee. After some discussion it was moved, seconded and carried that the Board should not appoint such a committee at this time.

The report of the Finance Committee meeting, held in Cleveland, January 5, 1925, was then presented as follows:

The Finance Committee of the A. S. S. T. held a meeting at the National Headquarters of the Society at ten o'clock on Monday morning, January 5, 1925.

There were present: Doctor Zay Jeffries, chairman; Messrs. A. O. Fulton, J. M. Watson, J. V. Emmons, A. G. Henry, exofficio, Mr. S. Bidle, and W. H. Eisenman.

Upon motion by Mr. Fulton, seconded by Mr. Watson and unanimously carried, it was recommended to the Board of Directors that the following advertising accounts, to the extent of $565.07, be written off:

The Atlas Steel Corp. (in receivership)	$ 60.00	
Cutler Steel Co. (liquidating)	83.25	
1923 Convention Accounts Receivable.		
The Atlas Steel Corp. (in receivership)	$ 60.60	
Bellevue Industrial Furnace Co.	25.00,	
W. E. Hamilton and Associates	366.50	
Union Electric Steel Co.	11.00	
Donner Steel Co.	1.00	$565.07

The 1925 budget was then presented for consideration, and after thorough discussion it was moved by Mr. Emmons, seconded by Mr. Henry and unanimously carried, that the budget as herewith submitted (see next page) be recommended to the Board of Directors for adoption.

Upon motion properly made, seconded and unanimously carried, it was recommended to the Board that the following list of materials on hand be accepted as inventory:

1284 bound volumes Transactions	$1400.00
Data Sheet paper stock (25 reams)	165.00
Data Sheet Binders (195)	292.50,
Transactions Paper Stock	
9 reams (450#) cover stock	85.50
86 reams (8600#) white stock	688.00
Office Furniture and Fixtures (present book value $948.44)	500.00
	$3131.00

It was moved, seconded and unanimously carried that the Finance Committee recommend to the Board of Directors that $10,000 of the funds at present in surplus be invested in Government securities to be purchased when the time seems propitious. The Committee further

went on record approving the action of the previous Board in suggesting the continuance of the policy that all advertisers in TRANSACTIONS whose accounts are more than 90 days in arrears, shall be denied the privilege of further use of TRANSACTIONS advertising pages.

The members of the Finance Committee then visited the safety deposit box, located at the Cleveland Trust Company, East End Branch, and found therein the following bonds:

Euclid Village Water Bonds (6%)	$ 3,000.00
Liberty Bonds 4¼ s	28,000.00
U. S. Treasury Certificates	2,015.00

The Committee also verified the savings accounts as listed below:

Cleveland Trust Co.	$ 3,109.28
The Equity Savings and Loan Co.	16,412.40
Union Trust Co.	1,126.14

Upon motion of Mr. Hughes, seconded by Mr. McCleary, and unanimously carried, the report was accepted and adopted.

Upon motion properly made, seconded and carried, the salary of the editor of TRANSACTIONS was increased from $4,200 to $4,800 a year.

Upon motion properly made, seconded and carried, the salary of the secretary to the Recommended Practice Committee was increased from $3,000 to $3,600 a year.

Upon motion properly made, seconded and carried, the salary of the secretary of the Society was increased from $7,800 to $9,000 a year.

The proposed budget for 1925 as prepared by the Finance Committee was then presented. Upon motion properly made, seconded and carried, the proposed income from advertising in TRANSACTIONS was increased from $30,000 to $32,400.

The budget as given and unanimously approved by the Board is as follows:

ANTICIPATED INCOME		
Dues (gross)	$37,000.00	
Transactions Advertising	32,400.00	
Transactions Sales	2,500.00	
Bindery Account	1,000.00	
Discounts Received	400.00	
Interest Received	2,300.00	
Data Sheets	3,000.00	
Miscellaneous	1,000.00	
1924 Convention	32,000.00	$111,600.00
ANTICIPATED EXPENSE		
Discounts Allowed	300.00	
Bindery Account	1,200.00	
Reprints	400.00	
Data Sheets	5,000.00	
Library	200.00	
Miscellaneous	200.00	
Transactions Advertising	1,600.00	
Transactions	30,900.00	
Secretary's Office	12,480.00	
President's Office	1,200.00	

Treasurer's Office	1,800.00	
Directors' Expenses	1,700.00	
National Committees	6,100.00	
Sectional Meetings	800.00	
Increase of Membership	500.00	
Bad Accounts	500.00	
Local Chapters Refund	14,800.00	
Incidentals	1,000.00	
Reserves		
1926 Convention	500.00	
1925 Convention	30,420.00	$111,600.00

Invitations for the spring sectional meeting were presented by the Schenectady and Philadelphia chapters. Upon motion properly made, seconded and carried, it was decided that the spring sectional meeting should be held in Schenectady, the tentative dates, May 28, 29 and 30, 1925, as named by the chapter being approved.

Upon motion properly made, seconded and carried, the meeting adjourned at 6.00 P. M.

FINANCIAL STATEMENT OF THE AMERICAN SOCIETY FOR STEEL TREATING FOR THE YEAR 1924

THE official report of Nau, Rusk and Sweringen, certified public accountants, covering the results of their audit of the books of the society is submitted herewith.

This statement again shows a very healthy condition of our finances, the Society working within its income and making substantial increases to its reserves and surplus.

The "Income and Expense Statement" shows an increase of about 20 per cent over our 1923 turnover which indicates a considerable increase in the society activities.

Full details of the audited report are herewith given. The official copy of this report is on file at the society offices and is open for the inspection of any interested members.

EXHIBIT A
BALANCE SHEET
AMERICAN SOCIETY FOR STEEL TREATING
December 31, 1924

ASSETS			
CASH			
The Cleveland Trust Co.:	(Commercial Account)	$ 1,853.27	
	(Savings Account)	3,109.28	
The Equity Savings & Loan Co. (Savings Account)		16,412.40	
The Union Trust Co. (Savings Account)		1,126.14	
Petty Cash		25.00	$22,526.09

INVESTMENTS			
Euclid Village, Ohio 6% Water Bonds	3,000.00		
U. S. Treasury Certificates (Par Value $2,500.00)	2,165.00		
U. S. Liberty Bonds	28,000.00	33,165.00	
ACCOUNTS RECEIVABLE			
Advertising	2,384.94		
Convention Accounts	795.95		
Sundry Accounts	631.25	3,812.14	
Accrued Interest on Investments		382.92	
INVENTORY—Bound Volumes and Stock for Transactions and Data Sheets		2,631.00	
FURNITURE AND FIXTURES (Book Value)		500.00	
PREPAID			
1925 Convention Expense	457.67		
Cincinnati Sectional Meeting	48.50	506.17	$ 63,523.32
LIABILITIES, RESERVES AND SURPLUS			
Accounts Payable		1,335.82	
Customers' Credit Balances for Bound Volumes not Billed		70.85	
Reserve for Dues Paid in Advance		10,000.00	
Permanent Convention Reserve		20,000.00	
H. M. Howe Medal Fund		3,000.00	
Reserve for Uncollectible Accounts Receivable		1,600.00	
Surplus (Balance January 1, 1924, $12,672.03..Addition for Year $15,444.62)		28,116.65	63,523.32

CERTIFICATE

We have made an audit of the books and accounts of the AMERICAN SOCIETY FOR STEEL TREATING for the year ended December 31, 1924, and in our opinion, the above Balance Sheet—Exhibit A, together with the annexed Income and Expense Statement—Exhibit B, correctly present its financial status at December 31, 1924, and a history of its financial transactions for the year then ended, basing the income from dues upon cash receipts and other income upon accruals.

Respectfully submitted,

NAU, RUSK & SWEARINGEN,
Certified Public Accountants.

EXHIBIT B

INCOME AND EXPENSE STATEMENT

AMERICAN SOCIETY FOR STEEL TREATING

Year ended December 31, 1924

INCOME		
Advertising	$27,701.65	
Membership Dues	34,871.83	
Boston 1924 Convention	49,557.85	
Transactions	1,777.75	
Bindery Sales	877.00	
Pins and Buttons	64.00	
Pencil Sales	62.75	
Data Sheets	1,942.90	
Discount on Purchases	342.88	
Interest Earned	2,337.69	
Interest on Howe Medal Fund	154.06	
Reprints and Miscellaneous Income	829.71	
Write-up Value of Bonds purchased at a Discount	82.50	$120,602.57
EXPENSES		
Returned to Local Chapters	13,767.19	
Support of Chapters	426.95	
Bindery	846.90	
Reprints	328.23	
Pencils	58.80	
Data Sheets	3,813.56	

Transactions		
Paper and Cover Stock	3,482.14	
Printing	10,708.67	
Cuts	1,199.61	
Postage	608.50	
Editor's Salary	4,200.00	
do Traveling Expense	275.84	
Clerical	1,752.25	
Advertising	1,261.56	
do Commissions	425.50	
Rent	650.25	
Stationery	216.20	
Office Supplies	86.46	
Executive Salary	1,950.00	
Mailing and Miscellaneous Expense	292.51	27,109.49
Secretary's Office		
Executive Salaries	3,120.00	
Rent	1,048.50	
Clerical	2,759.25	
Traveling	2,099.51	
Stationery	408.47	
Office Supplies	167.27	
Postage	1,073.95	
Telephone and Telegraph	346.10	
Auditing	165.00	
Miscellaneous	551.36	11,739.41
President's Office		
Miscellaneous Expense	....	73.00
Treasurer's Office		
Bookkeeper's Salary	1,098.75	
Rent	252.00	
Auditing	222.50	
Miscellaneous	159.54	1,732.79
Boston Convention		
Convention Expense—General	34,216.17	
Executive Salary	2,730.00	$ 36,946.17
Directors' Expense		
Traveling Expense	1,289.72	
Miscellaneous	44.25	1,333.97
National Committee		
Salary	2,891.67	
Constitution and By-laws	293.74	
Recommended Practice	388.29	
Publication	368.03	
Finance	134.50	
Research Findings	26.88	
Membership	33.67	
Tellers	48.50	
Traveling Expense	16.08	
Miscellaneous	111.35	4,312.71
Sectional Meetings		
Rochester	383.36	
Tri-City	237.52	620.88
Increase of Membership		22.53
Library		117.52
Uncollectible Accounts		957.57
Howe Medal Expense		137.41
Discount Allowed		221.95
Bank Exchange		5.62
Legal		7.50
1923 Convention Expense		129.36
Reduction in Value of Furniture and Fixtures		448.44
Balance—Carried to Surplus Account		15,444.62
		$120,602.57

EDUCATIONAL SECTION

IT has been pleasing to note the cordial response of the members to the announcement of the plan to incorporate in TRANSACTIONS, papers pertaining particularly to educational and informational subjects in addition to those of research and investigational character.

The first article in this new department was the installment issued last month by F. T. Sisco on the "Chemistry of Iron and Steel." The second installment is published in the March TRANSACTIONS beginning on page 363.

In addition to Mr. Sisco's valuable paper, there is included in this issue, beginning on page 379, an article by H. B. Knowlton, instructor in the Milwaukee Vocational School. Mr. Knowlton has had many years of experience both in industrial and educational lines, and the ease with which he portrays the fundamentals of metallurgy in a practical and understandable manner, is quite noteworthy.

Other announcements which undoubtedly will be of great interest to the members, will be made from time to time with reference to this section.

SPRING SECTIONAL MEETING

THE spring sectional meeting of the A. S. S. T. will be held in Schenectady, on Thursday, Friday and Saturday, May 28, 29 and 30, 1925.

The sectional meetings of the Society have been growing in interest as is indicated by the increased attendance at each successive meeting. The sectional meeting in Schenectady, due to the many points of interest and the fine program of papers being prepared, should be a guarantee of a large attendance. While details have not been definitely worked out, nevertheless it is planned to alternate plant visitation and technical sessions rather than follow the plan which has formerly been in effect, that of having all of the technical sessions on one day, and the plant visitation on the following.

The plants which it is contemplated at present to visit, will be those of General Electric Company, American Locomotive Works, and Ludlum Steel Company.

The new Hotel Van Curler in Schenectady will furnish a very desirable residence for visitors during their stay, as well as rooms for the technical sessions and the banquet.

A trip to Lake George is being planned, and many other attractive features will make the Schenectady sectional meeting one long to be remembered.

It is suggested that you plan to spend these three days in Schenectady.

THE 1925 ANNUAL CONVENTION—CLEVELAND

EVERY endeavor is being made to follow the regular policy of making every convention of the Society bigger than the one preceding. It is gratifying to note the greatly increased interest that is being aroused each year by this annual event in the iron and steel industry.

The Hotel Cleveland has been designated as headquarters. Papers for the technical sessions are being prepared and give every indication of maintaining the high standard that has been set by the papers of previous conventions.

The Exposition will be housed in Cleveland's new ten million dollar Public Auditorium. The floor plans have been sent out, and practically 95 per cent of the available space has been reserved.

The railroads have again granted fare and a half for the round trip.

Beginning with the April issue a series of articles on Cleveland and its points of interest will be presented in the TRANSACTIONS, but in the meantime mark off on your calendar the week of September 14, because Cleveland invites you and expects you to spend that week with her.

S. A. E. PRODUCTION MEETING

THE Society of Automotive Engineers have announced that they will hold their Production Meeting for 1925 at Cleveland during the week of September 14, 1925, with headquarters at the Winton Hotel. Much interest has been centered on the machine tool exhibit of the A. S. S. T. annual steel exposition and no doubt will attract many automotive production engineers especially since the S. A. E. meeting will be held during the week of this A. S. S. T. convention and exposition.

THE NOTCHED BAR TEST

BEGINNING on the opposite page of this issue of TRANSACTIONS is a very capable article by a noted German engineer of tests, namely, Dr. Max Moser of the Fried. Krupp Works, Essen, Germany. The data contained in this paper adds much to our present knowledge of the subject of notched-bar impact testing of materials.

In this work the author points out that when a notched-bar is broken by impact in a testing machine such as the Izod or Charpy, a considerable volume of metal in the neighborhood of the notched section absorbs the energy necessary to break the bar and that the practice of assuming that simply the area at the notched portion of the bar be used in computing the results is not correct.

This work is indeed fascinating and no doubt much valuable information respecting the impact values of materials in their relation to other physical properties will be forthcoming in the near future.

THE QUESTION BOX

MUCH interest has been shown in the Question Box department of TRANSACTIONS. We have received many favorable comments from our readers to the effect that they considered this department one of the most valuable in TRANSACTIONS. We frequently hear the statement that, "I am particularily interested to see the answer to this or that question." It is gratifying to know that this department is of service to our memvers, however it is felt that we are not getting support from our membership as a whole either in the receipt of questions or in answers to questions. Undoubtedly a large number do not realize that they can contribute to the enlarge of this valuable department in TRANSACTIONS.

The Question Box is intended for your use and it is urged that you avail yourself of the opportunity by making it work for you. Perhaps there are some members who would like to contribute answers but who feel that they do not care to have their name appear as a contributor. In this respect is may be said that in the case a contributor does not care to have his name appear as a contributor his answer will be published but his name will be withheld from publication. Your confidence and co-operation in making not only this feature but all other features of TRANSACTIONS a success is one way in which the Society will continue to progress and attain the goal for which we are aiming.

A NEW METHOD OF INTERPRETING NOTCHED BAR IMPACT TEST RESULTS

By Dr. Max Moser

Abstract

The author of this paper describes researches and methods of interpreting notched-bar impact test results. In this work, not only the area of the cross-section at the notch is used in computing the results of the impact of the pendulum, but also a considerable volume of metal surrounding the notch. This affected volume absorbs a certain portion of the impact energy.

Illustrations showing the effect of the impact on the area surrounding the notch are presented. Also tables and curves discussing this problem are included. A thorough discussion of the significance of the results obtained is given.

FOR controlling the effect of the heat treatment of steel, the notched-bar impact test is finding ever increasing favor. A notched-bar is brought into the blow path of a hammer and the impact energy "S" required for fracturing the bar measured.[1] According to the rules of the International Association for Testing Materials, the numerical result thus obtained, also called "resilience," is referred to the effective unit area of the test specimen. The numerical quantity in kilograms per square centimeter is called the "notch toughness" of the material in question.

In general, if our tests are to give reliable results, the following requirements must be fulfilled:

1 The stress conditions must be similar to those which the material is required to resist in service.

2 The method of measurement must be unquestionably suitable so as to preclude introducing misleading errors.

3 The interpretation of the numerical results must be correct.

No matter which of the arrangements now in use in impact

[1] See Symposium on Impact Testing of Materials, held at the 25th annual meeting of the American Society for Testing Materials.

A paper presented before the Boston Convention of the Society, September, 1924. The author, Dr. Max Moser, is testing engineer at the Fried. Krupp Works, Essen, Germany.

testing are employed, it may always be assured that the first two of the above conditions have been fulfilled. If, therefore, the testing of the toughness of materials by means of the notched-bar test has led to some very unpleasant contradictions, these evidently have their origin in an erroneous interpretation of the results.

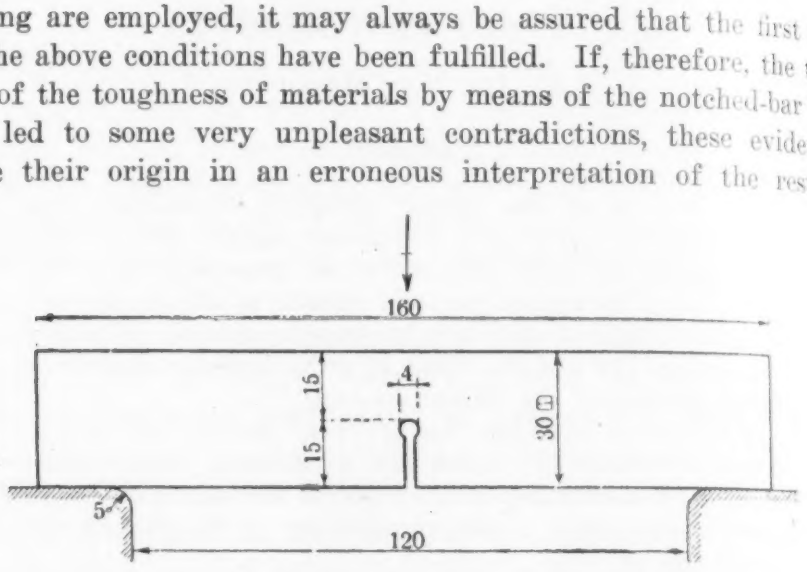


Fig. 1—Details of the Standard German Charpy Impact Test Bar.

This being so, it devolves upon the investigator to demonstrate which of the primary properties of the material find their expression in the so-called notch-toughness, and to build upon this basis a correct interpretation of these figures.

Of the experiments hitherto undertaken for this purpose, the test series carried out in the physical laboratory of Fried. Krupp Aktiengesellschaft have given a result that already throws some light on the matter and offers the basis for a successful utilization of the notch-impact test results. The testing arrangement consisted of a pendulum hammer, after Charpy, with 190 kilogram capacity. The standard test bars had the form and dimensions shown in Figs. 1 and 2.

Work Constant of the Unit Volume and Maximum Working Volume

The investigations started from the idea that the absolute values of the measured impact energy, when reduced, ought to be divided, not by an area, the cross section F, but by the volume that takes part in the absorption of energy. In this connection, it was necessary to bear in mind that the energy of the pendulum transmitted to the test bar on fracturing it does not deform the test piece in its entirety. Only a limited part V of the volume of the test piece can participate in the absorption of the energy, as the

adjacent masses on the right and left of the bottom of the notch are stiffened against any deformation. On carefully polished test pieces, the working volume V can be recognized quite clearly by the Hartmann lines appearing thereon (Fig. 3).

The tests carried out showed (as was already recognized by Schüle, who had not, however, followed the matter up), that the

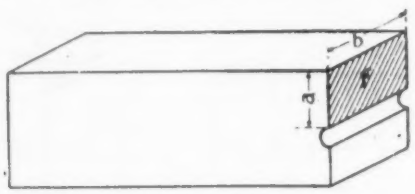


Fig. 2—Area at the Base of the Notch of the Standard German Charpy Impact Test Bar.

division of the absorbed impact energy by the working volume of the test piece gives for one and the same material a value $k_v = S:V$, which is constant within wide limits, independently of the form of the test pieces and their notches. The quantity of energy absorbed by the unit of the volume in the impact test, is thus

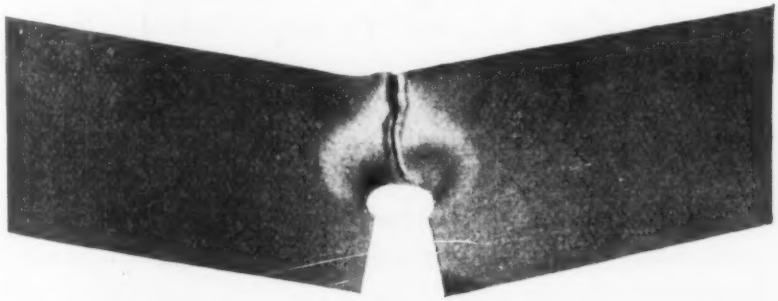


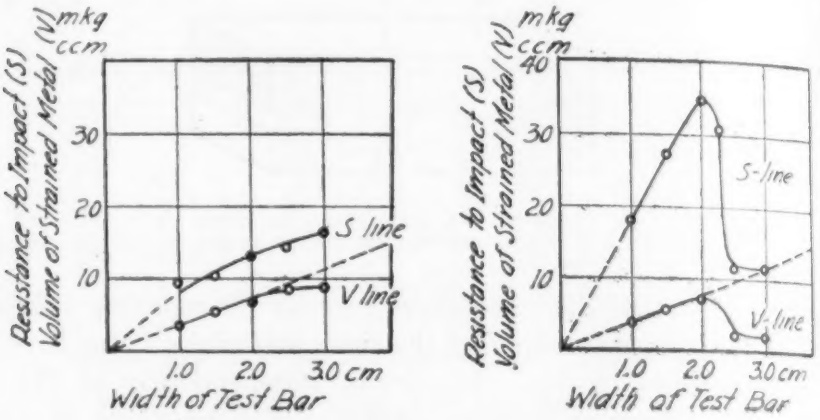
Fig. 3—Flow-Lines on an Impact Test Bar, Showing the Volume of Strained Metal.

shown to be a constant which is peculiar to the material and characterizes it. The value of the "work-constant" of the unit volume, can only be changed by a treatment influencing the nature of the material, for instance by a heat treatment.

The impact energy measured in an impact test is the product of the multiplication of this work-constant of the unit volume by the number of the volume units absorbing energy. If, therefore, tests with a given material show that the value of the impact energy is not in proportion to the size of the test piece, or that it changes with the same test piece according to the form of the

notch, these phenomena can only be due to variations of the working volume V.

Further investigation showed, in fact, that the shape of all impact energy curves plotted had its foundation in the shape of V-lines, which represent the volume, in cubic centimeters, of the part marked on the fractured test pieces by the Hartmann-lines.



Figs. 4 and 5—Volume of Strained Metal and Resistance to Impact Curves for Steels of Two Different Degrees of Toughness.

The diagrams (Figs. 4, 5 and 6) may illustrate this for three different kinds of steels. The figures show the behavior of the three kinds of steels in the impact test, where the test piece illustrated in Fig. 1, gradually increases in width from 1 to 3 centimeters, while the other conditions remain the same. The essential difference in the impact energy lines (S-lines) of the three materials can be observed in quite an analogous manner in the working volume lines (V-lines).

The investigation of the question as to what factors in turn determine the shape of the V-lines in every particular case, led to the discovery of an important law governing the entire notch test question: For every notched test piece of definite dimensions and shape of notch, there exists a maximum value of the volume participating in the absorption of energy. This maximum value comprises an exactly determinable number of volume units; it is evidently subject to certain physico-mechanical laws and is independent of the nature of the material. For the test piece represented in Fig. 1 the maximum value is 12.5 cubic centimeters. With test pieces of different width, but otherwise identical, the maximum value is proportional to the width of the test piece.

Referring to Figs. 4 and 6, we find a straight line (marked in dashes) drawn tangentially to the V-lines. This straight line is the proportional representing the "maximum working-volume line" for the shape of test piece used in the tests, with widths varying from 1 to 3 centimeters. It will be perceived how with the steel of

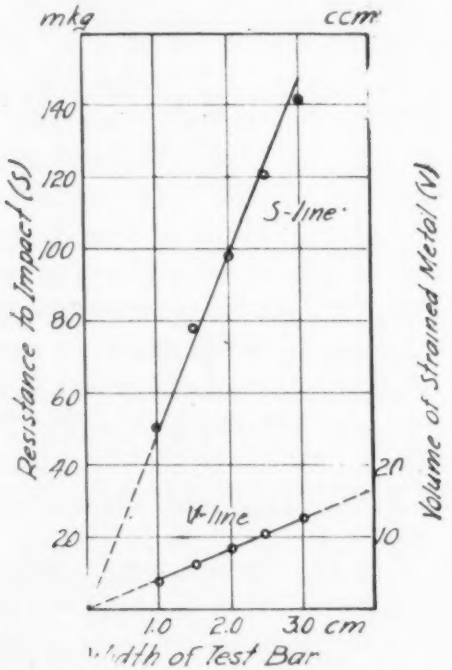


Fig. 6—Volume of Strained Metal and Resistance to Impact Curves for a Steel of a Different Degree of Toughness from Those of Figs. 4 and 5.

Fig. 6, the V-values coincide with this proportional over the whole range of the test. No matter whether the test pieces are narrow or wide, the number of the volume units participating in the absorption of energy with this material always attain the physico-mechanically possible maximum value. The two other steels, on the contrary, reach the maximum value only with narrow test pieces; with the larger ones they, in different ways, drop below the maximum.

Speed of Impact and Velocity of Strain Propagation

Light was thrown on these relations by a series of tests, the results of which are illustrated in Fig. 7.

The tests in question were carried out with test pieces of the

material of Fig. 5. The shape of the test pieces and the radius of the notch were precisely the same as for the first tests. The speed of impact, however, was reduced. On the diagram in Fig. 7 the familiar S- and V-lines from the earlier diagram are shown as

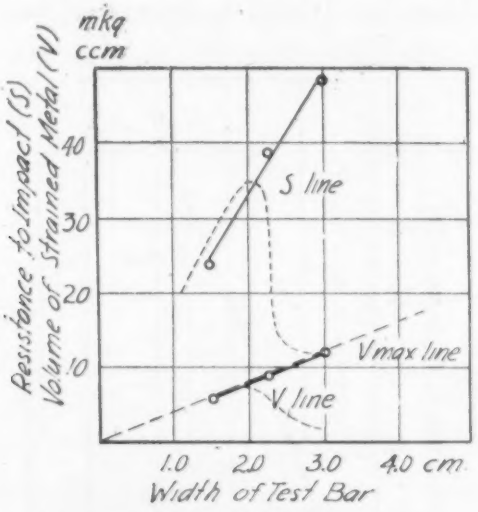


Fig. 7—Curves Showing Effect of Lowering the Speed of Impact on the Steel of Fig. 5.

dotted lines, as well as the dashed maximum volume line. Into the diagram thus prepared were then drawn heavy lines representing the results of the tests carried out with the lower striking velocity. The remarkable change in the shape of the curves at once strikes the eye and shows that decreasing the speed of impact allowed the material to participate in the absorption of energy with the volume corresponding to the maximum value line, even in the case of the wider test pieces.

Continuance of these investigations showed the phenomenon observed here to be generally valid and revealed a second law governing the entire question of the notch impact test, namely, that the shape of the working volume curves and, consequently, of the impact energy curves of a given material depends upon the ratio of the speed of impact to the velocity of strain propagation of the material.

With a lower striking velocity the impact process takes effect slowly;[2] the material has comparatively ample time for the absorp-

[2]It is true that sufficient data are not yet available to explain the course of the fracturing process in terms of time, but it is doubtless substantially dependent on the velocity with which the pendulum hammer transmits the energy to be absorbed to the test piece. See, inter alia Hadfield, etc., minutes of Proceedings of the Institution of Civil Engineers, Vol. 211, meeting 1920-21, reports.

tion of the energy. With a high striking velocity the material is required to change its form in a very short time. The speed with which materials, generally speaking, are able to change their form and thus to absorb work is, however, widely different and ranges through numberless intermediate stages. With materials that may change that form quickly, the volume of the test piece participating in the absorption of energy belongs to the maximum values even at high impact velocities, while test pieces made of materials which are slow in changing their form cannot, within the short time available, reach the highest volume values, if the ratio of their width to their thickness exceeds a certain value. Only when there is sufficient time available can the change of form of the slow material extend to the whole number of volume units corresponding to the proportionality. Evidently there exists for every steel a certain limit of speed of impact, the overstepping of which determines its behavior, and the position of which depends on the agility with which the material can change its shape, or the velocity of strain propagation. It is this peculiarity, the higher or lower velocity of strain propagation, which, as a second factor, determines the result of the impact test, as on it depends the extent to which the material on impact is able to change its form within the time available or, in other words, the amount of energy which the test piece can absorb before being ruptured.[3]

Significance of the Results Obtained

The work-constant and propagation velocity are properties of the material. By their numerical determination, which will be dealt with later on, a material is fully characterized as regards its nature and its behavior. The knowledge of one of these two values alone is not sufficient to completely characterize the material; both values must be known.

It might be objected that the determination of the notch toughness in accordance with the rules of the Association takes both values into account, the impact energy being the product of both. The answer to that is, that the numerical value thus found does not afford any information about the respective influence of either value. There could, for instance, certainly be found two

[3]The definition of "velocity of strain propagation" thus introduced has meanwhile been theoretically defined by Ludwig, Stahl und Eisen 43 (1923), p. 1427. Mailänder, Kruppsche Monatshefte 5 (1924) has re-examined and confirmed it by means of tests.

different steels, one of them able to deform very quickly, but with a low work-constant of the unit volume and the other one sluggish in changing shape, but with a high work-constant, with the result that the products of the work-constants and the number of the participating volume units would have the same value for both steels. The notched-bar test would, therefore, give the same impact energy (resilience) and the same notch toughness in the case of both steels, while in reality both steels would be entirely different with regard to their nature, range of usefulness and behavior under certain exigencies of service.

If, however, we analyze the impact results according to the two factors determining them, we are able to characterize the material exactly by the separate evaluation of these two constants, thus allowing the designer to select a material suitable for his requirements. This may be illustrated by two rather opposite instances, a railway axle and a boiler plate.

A railway axle is required to stand up under sudden, rapid shocks in ordinary use or on sudden violent impact against an obstacle; it should, at the worst, be only deformed. This would, therefore, be a question of the behavior of the material against high striking velocity and, therefore, materials which can deform rapidly are required. Within this group, under certain circumstances (good spring suspension, etc.) materials of relatively low work-constant will, perhaps, be sufficient, if the construction has to be low priced. If the question of price may be neglected, a material which at the same time possesses a high work-constant is to be preferred. It follows that the best material for a railway axle is a heat treated alloy steel combining a high velocity of strain propagation with a high work-constant.

In the case of a boiler plate, very low striking velocities come into play. The slow "breathing" of the boiler can be followed even by a slow-working material with its slow change of form. But a high work-constant is favorable. For boiler plates, therefore, slow-working steels are suitable and from amongst these, one with a high work-constant should be chosen.

Calculation of Work-Constant and of Velocity of Deformation (Abridged Method)

The work-constant can without difficulty be indicated for every

kind of material. For this purpose, we have only to divide an impact energy value, which can be supposed with certainty to lie on the line of proportionality, by the number of participating volume units taken from the maximum working volume line. We may, for instance, expect this from steel, if the test pieces have square impact cross sections.

As a numerical measure for the velocity of strain propagation we may take that speed of impact, which may not be exceeded without the material deviating from the maximum working volume line. It is true that for a correct determination of the "limiting speed of impact" the carrying out of several series of tests is necessary, as well as apparatus for this purpose. More suitable for practical purposes is a method based on the already discussed diagrams of Figs. 4 to 6. The quickness or the slowness of a material finds its expression in the fact, that in one case the working volume value of the wide test piece reaches the maximum value, while in the other case it deviates from it more or less; we may, therefore, define the percentage reached as the degree of velocity. A material, which in wide test pieces reaches the maximum value of the working volume, may, therefore, be said to possess a velocity of propagation of 100 per cent, slower materials correspondingly less.

Summing up, the abridged process for determining the two material values operates as follows: Two test pieces are broken, one with square impact section (1.5×1.5 centimeters) and the other with an impact cross section of double width (3.0×1.5 centimeters), while the striking velocity is the same for both test pieces. We divide the impact energy value obtained with the square test piece by 6.3 cubic centimeters (the working volume), thus obtain the work-constant of the material in kilograms per cubic centimeter. Dividing the impact energy of the wider test piece, by this figure, we find the working volume of the latter, which expressed as a percentage of the respective V-max (12.5 cubic centimeters) gives the relative velocity of the material.

A few examples will serve to make this abridged method clear.

A square test piece of a certain steel A gave an impact energy of 33 kilograms, while a test piece of double width gave an impact energy of 62.5 kilograms. We find, by means of the calculation outlined above, that the quantity of energy absorbed by the unit volume is $33 \div 6.3 = 5.2$ kilograms per cubic centimeter, the relative

velocity $[(62.5 \div 5.2) \div 12.5] \times 100 = 95$ per cent. Consequently, the material absorbs the energy very fast; but should not be required to absorb too large a quantity of energy.

Steel B gave an impact energy of 78.4 kilograms, with the square test piece, with the test piece of double width an impact energy of 150 kilograms. The work-constant was calculated to be 12.4 kilograms per cubic centimeter, the relative velocity to be 97 per cent.

We are, therefore, here again in the presence of a quick material, but this time it is one that is at the same time capable of absorbing large quantities of energy.

Steel C gave, with the square test piece, an impact energy of 32 kilograms and with test pieces of double width an impact energy of 15 kilograms. The work-constant per unit volume of 5.1 kilograms per cubic centimeters is, practically speaking, equal to that of steel A. But this steel C, in contrast to A, is comparatively sluggish; the calculation of the relative velocity gives 23.4 per cent.

A surprisingly low value of the work-constant was found in a steel D having a relative high velocity constant. The impact energy of the square test piece was 11.3 kilograms, that of the test piece of double width 16.5 kilograms, so that the work-constant is 1.8 kilograms per cubic centimeter and the relative velocity 73 per cent.

Table I and Fig. 8 show the characteristic values of the four steels and illustrate their different natures.

Table I

Designation of the Steel	Work-constant meter kilograms per cubic centimeter	Intermediate calculation	Relative velocity per cent
A	$33 \div 6.3 = 5.2$	$62.5 \div 5.2 = 11.9$	$\frac{11.9}{12.5} \times 100 = 95$
B	$78.4 \div 6.3 = 12.4$	$150 \div 12.4 = 12.1$	$\frac{12.1}{12.5} \times 100 = 97$
C	$32 \div 6.3 = 5.1$	$15 \div 5.1 = 2.94$	$\frac{2.94}{12.5} \times 100 = 23$
D	$11.3 \div 6.3 = 1.8$	$16.5 \div 1.8 = 9.2$	$\frac{9.2}{12.5} \times 100 = 73$

The two steels C and D, be it said in passing, are a classical example of what has been stated under the heading, "Significance of the Results Obtained." The notch toughness computed by the usual method from the impact energy is the same for these two steels (3.3 and 3.7 kilograms per square centimeter respectively) and yet in practical use, we should meet with fundamental differences which might lead to very unpleasant results. The method of evaluating the impact energy by means of resolution into the two component factors clearly shows its superiority in this example.

A very convenient auxiliary for use with the abridged method

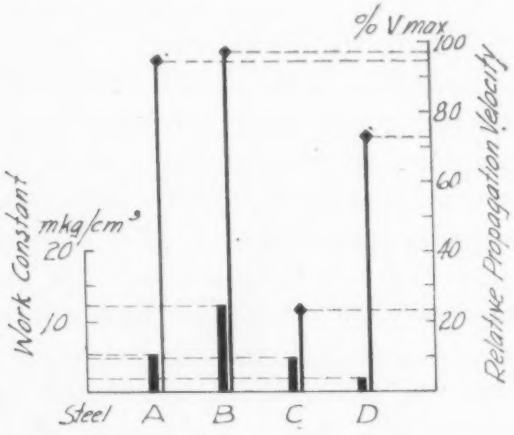


Fig. 8—Comparison of Four Steels Based on the Abridged Method.

is a table like the one reproduced in Table II; on the horizontal abscissa axis are entered the impact energy values found with the narrow test piece, on the vertical ordinate axis the impact energies obtained with the wider one. The intersection of the two respective columns gives the values sought. To enable the lower values to be read off more accurately, the initial region of a second table (Table III) has been subdivided still further.

Influence of Various Heat Treatments and Various Test Temperatures on the Material Constants

It is a well-known fact that the impact resistance of a material can be increased by quenching and tempering and lowered by overheating. But the temperature at which the notch impact test is carried out, has likewise proved in the case of most steels to

be essential for the result. Reference is herewith made to the extensive and very interesting tests carried out by Langenberg.[1]

Naturally, it appeared desirable to ascertain the cause of this change of the impact resistance with different heat treatments and change of test temperature; i. e., to show whether it is due to the effect upon the work-constant, or on the velocity of strain propagation of the material, or on both properties at the same time. So far as the questions connected with *heat treatment*, we will, out of a number of tests carried out for this purpose, deal more in detail with the following and the conclusions to which they lead.

A carbon steel with 0.30 per cent carbon, in bar form, was investigated in three different states: annealed, overheated, quenched and tempered. Figs. 9, 10 and 11 show their microstructures. The test pieces were carefully prepared and highly polished for the determination of the working volume. Fig. 12 offers, to begin with, a summary of the impact energy values obtained with the Charpy pendulum. With the normally annealed and with the quenched and tempered material the impact energy increased in proportion to the width of the test piece; in both states the steel, therefore, proved to belong to the category of quick-working material; in the case of overheated steel, the impact energy decreased in the wider test pieces; owing to the overheating, the steel, therefore, became slow-working. A deeper insight into these relations will be gained by examining Fig. 13, which illustrates the working volume quantities. Besides the volume curves of the three materials, a thinly dotted line has been inserted: the maximum volume line. We see at once that the working volume values of the annealed steel and of the quenched and tempered steel are equal, and that with all widths of test pieces they have reached the maximum value. The degree of both steels is, in round figures, 100 per cent. Subsequent overheating of the normally heated steel has, however, reduced the relative velocity to 23 per cent. Now, in order to judge the work-constant value, the values taken from diagram Fig. 12 must be divided by those taken from diagram Fig. 13. Here it is surprising to find that the work-constant of the normally annealed steel has practically not been changed by overheating; it is, as before, about 4.5 kilograms per cubic centimeter. On the

[1]Papers read before the American Iron and Steel Institute, May and October, 1923.

	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72	75	78	79	
3	0.48	0.95	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	50	26	17	13	10	8	7	6	5.6	5.04	4.6	4.3	3.9	3.6	3.4	3.2	3	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2	1.9	1.9	% Relative Velocity
6	0.48	0.95	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	100	50	34	26	20	17	14	13	11	10	9	8	7.8	7.2	6.8	6.3	5.9	5.6	5.3	5	4.8	4.6	4.4	4.2	4	3.9	3.8	% Relative Velocity
9	...	0.95	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	76	51	38	30	25	22	19	17	15	14	13	12	11	10	9.5	9	8.4	8	7.5	7.2	6.9	6.6	6.3	6	5.9	5.8	% Relative Velocity
12	...	0.95	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	100	69	50	40	33	29	26	22	20	18	17	15	14	13	13	12	11.1	10.6	10	9.6	9.2	8.8	8.4	8	7.8	7.7	% Relative Velocity
15	...	...	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	86	63	50	41	36	32	28	25	23	21	19	18	17	16	15	14	13	12.6	12	11.5	11	10.4	10	9.8	9.6	% Relative Velocity
18	...	...	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	100	76	60	50	44	38	34	30	28	25	23	21	20	19	18	17	16	15	14	14	13	12.8	12	11.7	11.5	% Relative Velocity
21	...	...	...	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	88	70	58	51	44	39	35	32	30	27	25	24	22	21	20	19	18	17	16	15	14.7	14	13.7	13.4	% Relative Velocity
24	...	...	...	1.9	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	100	80	66	58	51	45	39	37	34	31	29	27	25	24	22	21	20	19	18	18	17	16	15.6	15.3	% Relative Velocity
27	...	...	...	...	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	90	74	65	57	50	45	42	38	35	32	30	28	27	25	24	23	22	21	20	19	18	17	17	% Relative Velocity
30	...	...	...	...	2.4	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	100	82	73	63	56	50	46	42	39	36	34	32	30	28	27	25	24	23	22	21	20	19	19	% Relative Velocity
33	...	...	...	...	...	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	91	80	69	61	55	50	46	43	39	37	35	33	31	29	28	26	25	24	23	22	21	21	% Relative Velocity
36	...	...	...	...	...	2.9	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	100	87	76	67	60	55	50	46	43	41	38	36	34	32	30	29	28	26	26	24	23	23	% Relative Velocity
39	...	...	...	...	...	...	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	96	82	72	65	60	55	50	47	44	41	39	37	35	33	31	30	29	28	26	25	25	% Relative Velocity
42	...	...	...	...	...	...	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	100	88	78	70	65	59	54	50	47	44	42	39	37	35	34	32	31	30	28	27	27	% Relative Velocity
45	...	...	...	...	...	...	...	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	94	84	75	69	63	58	54	51	47	45	42	40	38	36	35	33	32	30	29	29	% Relative Velocity
48	...	...	...	...	...	...	...	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	100	89	80	74	67	62	57	54	50	48	45	43	40	38	37	35	34	32	31	31	% Relative Velocity
51	...	...	...	...	...	...	...	...	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	95	85	78	72	66	60	58	53	50	47	45	43	41	39	37	36	34	33	33	% Relative Velocity
54	...	...	...	...	...	...	...	...	4.3	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	100	90	83	76	70	64	61	57	53	50	48	46	43	41	40	38	36	35	34	% Relative Velocity
57	...	...	...	...	...	...	...	...	...	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	95	88	80	74	68	65	60	56	53	51	48	46	44	42	40	38	37	36	% Relative Velocity
60	...	...	...	...	...	...	...	...	...	4.8	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	100	92	84	77	72	68	63	59	56	53	51	48	46	44	42	40	39	38	% Relative Velocity
63	...	...	...	...	...	...	...	...	...	...	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	97	88	81	75	71	66	62	59	56	53	50	48	46	44	42	41	40	% Relative Velocity
66	...	...	...	...	...	...	...	...	...	...	5.2	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	100	93	85	79	74	69	65	61	59	56	53	51	48	46	44	43	42	% Relative Velocity
69	...	...	...	...	...	...	...	...	...	...	...	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	97	89	82	78	73	68	64	61	59	55	53	51	48	46	45	44		% Relative Velocity
72	...	...	...	...	...	...	...	...	...	...	5.7	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	100	93	86	81	76	71	67	64	61	58	55	53	50	48	47	46		% Relative Velocity
75	...	...	...	...	...	...	...	...	...	...	...	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	97	90	85	79	74	70	66	63	60	58	55	53	50	49	48		% Relative Velocity
78	...	...	...	...	...	...	...	...	...	...	...	6.2	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	100	93	88	82	77	73	69	66	62	60	57	55	52	51	50	% Relative Velocity
81	...	...	...	...	...	...	...	...	...	...	...	...	...	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	97	91	85	80	75	72	68	65	62	59	57	54	53	52	% Relative Velocity
84	...	...	...	...	...	...	...	...	...	...	...	...	...	6.7	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	100	95	88	83	78	75	71	67	65	62	59	56	55	54	% Relative Velocity
87	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	98	92	86	81	77	73	69	67	64	61	58	57	56	% Relative Velocity
90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7.1	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	95	89	84	80	76	72	69	66	63	60	59	58	% Relative Velocity
93	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	98	92	87	83	78	74	71	68	66	62	60	59	% Relative Velocity
96	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7.6	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	95	89	85	81	77	74	70	68	64	62	61	% Relative Velocity
99	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	98	92	88	83	79	76	73	70	66	64	62		% Relative Velocity
102	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8.1	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	95	91	86	81	78	75	72	68	66	65		% Relative Velocity
105	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	98	93	88	84	81	77	74	71	68	67		% Relative Velocity
108	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8.6	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	96	91	86	83	79	76	73	70	69		% Relative Velocity
111	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	99	94	89	85	81	78	75	72	71		% Relative Velocity
114	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	102	96	91	88	84	80	77	74	73		% Relative Velocity
117	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	99	94	90	86	82	79	76	75		% Relative Velocity
120	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9.5	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	101	96	92	88	84	81	78	77		% Relative Velocity
123	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	99	94	90	86	83	80	79		% Relative Velocity
126	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	101	97	92	88	85	82	81		% Relative Velocity
129	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10.4	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	95	90	87	84	83		% Relative Velocity
132	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	96	93	89	86	85		% Relative Velocity
135	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	98	95	91	88	86		% Relative Velocity
138	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10.9	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	97	93	90	88		% Relative Velocity
141	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11.4	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	99	95	92	90		% Relative Velocity
144	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	97	94	92		% Relative Velocity
147	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	99	96	94		% Relative Velocity
150	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11.9	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	98	96		% Relative Velocity
153	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.3	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100	98		% Relative Velocity
156	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12.5		Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	100		% Relative Velocity

Impact Values Found with Wide Test Piece

S30

Impact Values Found with Narrow Test Pieces

S15

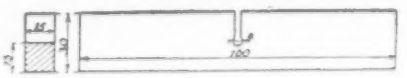


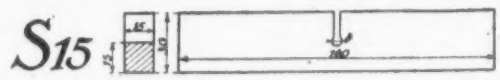
Table III

Work-Constant and Relative Velocity for Narrow and Wide Notched Bars

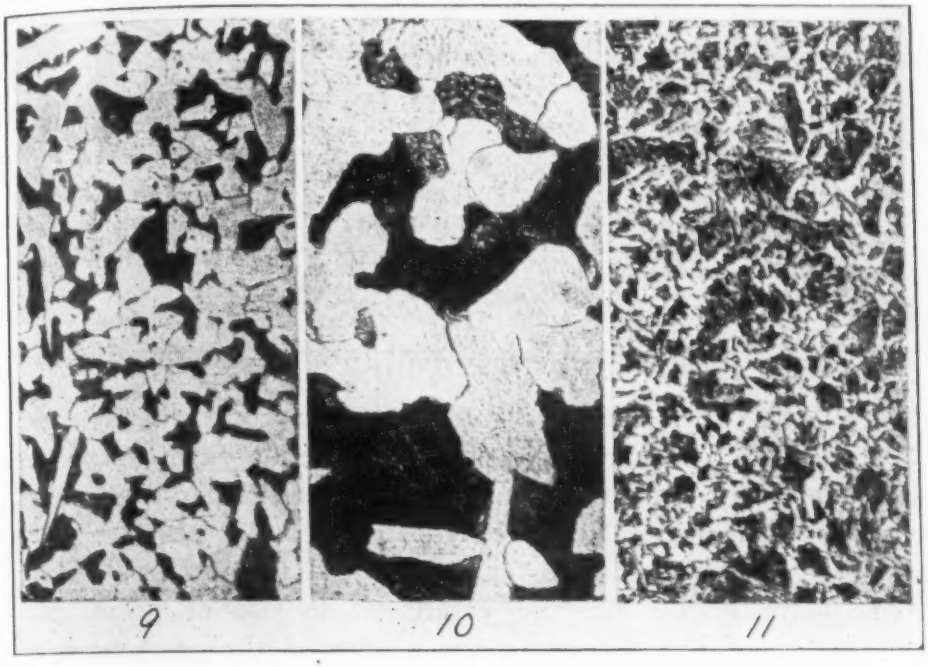
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	0.158	0.318	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	51	25	17	12	10	8	7	6	5.7	5	4.6	4.3	3.9	3.6	3.3	3.2	3	2.8	2.7	2.5	% Relative Velocity
2	0.158	0.318	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	100	50	33	25	20	17	14	12	11	10	9	8.5	7.8	7.3	6.7	6.4	6	5.5	5.4	5	% Relative Velocity
3	...	0.318	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	76	50	38	30	25	22	19	17	15	14	13	12	11	10	9.6	9	8.3	8	7.5	% Relative Velocity
4	...	0.318	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	100	67	50	40	34	29	25	24	20	18	17	15	14	13	12.8	12	11	11	10	% Relative Velocity
5	...	...	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	82	63	51	42	36	31	29	25	23	21	19	17	17	16	15	14	13	12	% Relative Velocity
6	...	...	0.48	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	100	76	61	50	43	38	34	30	27	25	23	22	20	19	18	17	16	15	% Relative Velocity
7	...	...	...	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	88	71	59	50	44	40	35	32	29	27	25	23	22	21	19	19	17	% Relative Velocity
8	...	...	...	0.635	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	100	81	67	58	50	46	40	37	34	31	29	27	25	24	22	22	20	% Relative Velocity
9	...	...	...	...	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	91	76	65	57	51	45	41	38	35	33	30	29	27	25	24	22	% Relative Velocity
10	...	...	...	...	0.79	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	100	84	72	63	57	50	46	43	39	36	33	32	30	28	27	25	% Relative Velocity
11	...	...	...	...	...	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	93	79	69	63	55	50	46	43	40	37	35	33	30	29	27	% Relative Velocity
12	...	...	...	...	...	0.95	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	100	86	76	69	60	55	50	47	44	40	38	36	32	32	30	% Relative Velocity
13	...	...	...	...	...	...	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	94	82	74	65	59	55	50	47	43	42	39	36	35	32	% Relative Velocity
14	...	...	...	...	...	...	1.11	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	100	88	80	70	64	59	54	51	47	46	42	39	37	35	% Relative Velocity
15	...	...	...	...	...	...	...	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	94	86	75	69	63	58	55	50	48	45	41	40	37	% Relative Velocity
16	...	...	...	...	...	...	...	1.27	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	100	91	80	73	67	62	58	53	51	47	44	43	40	% Relative Velocity
17	...	...	...	...	...	...	...	...	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	97	85	78	72	66	62	57	54	50	47	45	42	% Relative Velocity
18	...	...	...	...	...	...	...	...	1.4	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	100	90	82	76	70	65	60	58	53	50	48	45	% Relative Velocity
19	...	...	...	...	...	...	...	...	...	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	95	87	80	74	69	63	61	56	52	51	47	% Relative Velocity
20	...	...	...	...	...	...	...	...	...	1.6	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	100	91	84	78	73	67	64	59	55	53	50	% Relative Velocity
21	...	...	...	...	...	...	...	...	...	...	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	96	88	82	76	70	67	62	58	56	52	% Relative Velocity
22	...	...	...	...	...	...	...	...	...	...	1.75	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	100	92	86	80	73	70	65	61	59	55	% Relative Velocity
23	...	...	...	...	...	...	...	...	...	...	...	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	96	89	84	77	74	68	64	61	57	% Relative Velocity
24	...	...	...	...	...	...	...	...	...	...	...	1.9	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	100	93	87	80	77	71	66	64	60	% Relative Velocity
25	...	...	...	...	...	...	...	...	...	...	...	..	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	97	91	83	80	74	69	67	62	% Relative Velocity
26	...	...	...	...	...	...	...	...	...	...	...	..	2.06	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	100	94	87	83	77	72	69	65	% Relative Velocity
27	...	...	...	...	...	...	...	...	...	...	...	..	..	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	98	90	86	80	74	72	67	% Relative Velocity
28	...	...	...	...	...	...	...	...	...	...	...	..	..	2.2	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	100	93	90	83	77	75	70	% Relative Velocity
29	...	...	...	...	...	...	...	...	...	...	...	..	..	..	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	97	93	86	80	77	72	% Relative Velocity
30	...	...	...	...	...	...	...	...	...	...	...	..	..	..	2.4	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	100	96	89	83	80	75	% Relative Velocity
31	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	2.5	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	100	92	86	83	77	% Relative Velocity
32	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	95	88	85	80	% Relative Velocity
33	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	98	91	88	82	% Relative Velocity
34	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	2.7	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	100	94	91	85	% Relative Velocity
35	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	97	93	87	% Relative Velocity
36	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	2.9	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	100	96	90	% Relative Velocity
37	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	3	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	99	92	% Relative Velocity
38	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	95	% Relative Velocity
39	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	97	% Relative Velocity
40	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	3.2	Work-Constant
	...	...	...	...	...	...	...	...	...	...	...	..	..	..	..	..	..	..	..	100	% Relative Velocity

Impact Values Found with Wide Test Piece

Impact Values Found with Narrow Test Pieces



contrary, with quenched and tempered steel the work-constant of the original normally annealed steal has become about three



Figs. 9 to 11—Microstructures of Test Bars (0.3 Per Cent Carbon) After Different Heat Treatments.

Fig. 9 Annealed | Fig. 10 Over Heated | Fig. 11 Heat Treated

times as high, 13 kilograms per cubic centimeter instead of 4.5. Table IV places the values side by side.

Combining the examination of the diagrams and of Table IV with the reflection that the overheating, as shown also by Figs. 9 and 10, has not changed the nature of the microstructure itself, but only its size, whilst quenching and tempering (Fig. 11) has brought about a radical change in both, we are led to the following conclusions:

I A heat treatment that does not change the nature of the microstructure, but only its size, influences in the first place the velocity of strain propagation of the material; with growing size of grain, this velocity decreases.

II A heat treatment that changes not only the size, but also the nature of the microstructure, further changes the quantity of work that can be absorbed by the volume unit.

Let us consider an instance taken from forging practice. A forging of large dimensions showed on test at one end 29.0 kilograms per square centimeter notch toughness, at the other end 7.3. The forging was then tested at both ends by notch impact by the "abridged method." Both ends gave exactly the same value of the work-constant (6.55 kilograms per cubic centimeter) but different relative velocities of 35 and 9 per cent. The conclusion was that the two ends had been finished at different temperatures giving different results as to size of grain. An examination of the microstructure confirmed the correctness of this supposition (Figs. 14 and 15).

Table IV

State of the material	Work-constant meter kilograms per cubic centimeter	Degree of resilience per cent
Normally annealed	(5—) 4.5	about 100
Overheated	4.5 (—5)	23
Tempered	13	about 100

To the practical man desirous of improving unsatisfactory notch toughness of a forging, the above shows the expediency of examining the microstructure of the material of the forging. The nature, as well as the grain size of the structure will, with the help of the above lines of guidance, show him whether annealing will suffice, or whether quenching and tempering is necessary. He will above all recognize, whether it is possible to increase by heat treatment the notch toughness of the respective piece in comparison with the present notch toughness.

Regarding the influence of the test temperature the question as to which of the two properties of the material on which the impact work depends is influenced by the change of temperature, was very clearly answered by a series of tests made with carbon steel of medium toughness. The test temperatures were, minus 20 degrees Cent., plus 20 degrees Cent., plus 100 degrees Cent., plus 200 degrees Cent., plus 300 degrees Cent., plus 450 degrees Cent. At each of these temperatures the material was investigated by the "abridged method." Fig. 16 shows that an increase

of temperature causes at first the impact work to increase with a maximum at about 200 degrees Cent. Analogous to the Langenberg tests, the impact work is again lower, as soon as the test

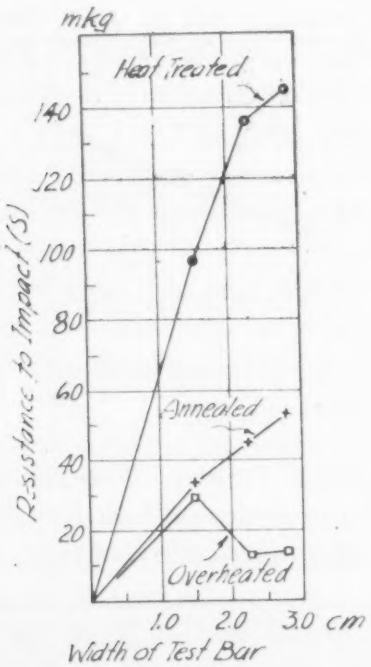


Fig. 12 — Curves Showing the Effect of Heat Treatment on Resistance to Impact.

temperature passes a certain value. Figs. 17 and 18 give the desired insight into the fundamental conditions and show that work-constant and velocity of propagation, both change with test temperature and in the same way. The variations of the resilience values with varying test temperatures are consequently dependent on variations of both factors determining them.

Do Relations Exist Between Notch Test and Tensile Test?

From the beginning there has been no lack of investigation of the question as to whether a bridge could be thrown from the notch impact test to the static tensile test, which is the prevailing method of testing materials. These investigations gave, without

exception, very contradictory and mostly negative results, and were bound to do so, as long as the operators worked on the

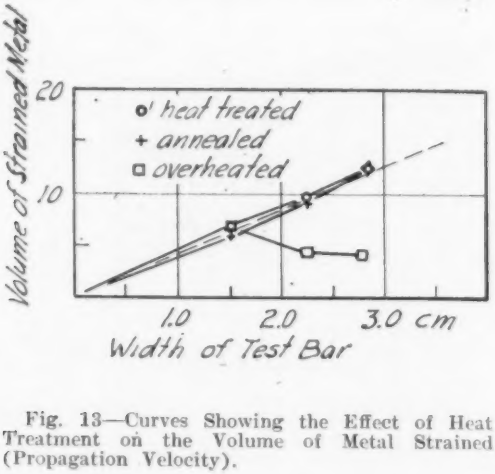
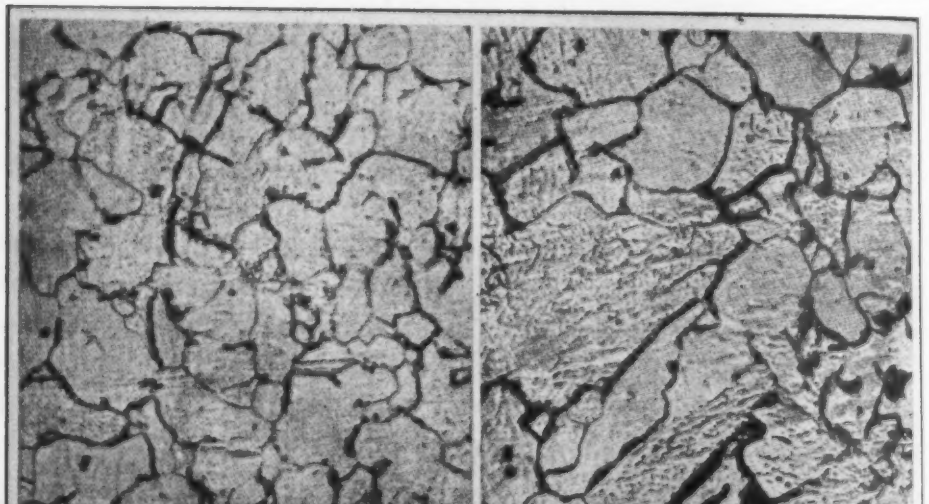


Fig. 13—Curves Showing the Effect of Heat Treatment on the Volume of Metal Strained (Propagation Velocity).

complex notch toughness values. The resolution of the impact test results into a factor dependent on time, the velocity of strain propagation and a factor independent of time, the work-constant, be-



Figs. 14 and 15—Photomicrographs of Forged Bar Which Gave a Resistance to Impact on One End of 29 mkg/sq. cm. and 7.3 mkg/sq. cm. on the Other End. 200 x.
Fig. 14—Work-Constant 6.55 mkg/cu. cm. Relative Velocity 35 Per Cent. Fine Grained.
Fig. 15—Work-Constant 6.55 mkg/cu. cm. Relative Velocity 9 Per Cent. Coarse Grained.

gins to throw some light on this question also. In an earlier publication, entitled, "Zur Gesetzmässigkeit der Kerbschlagprobe," it has been stated that between the work-constant to be extracted from the impact figures, on one side, and the contraction in area measured in the tensile test, on the other side, there seemed to exist a definite relation. The tests carried out up to the present have confirmed the existence of a law connecting the work-constant and the contraction. They have further demonstrated that this relation is changed by quenching and tempering the steel. Annealing processes that did not change the nature of the structure but only its size, did not affect the relation; an observation that sheds new light on what has been said about the influence of the heat treatment. Fig. 19 illustrates the test values showing the connection between contraction and work-constant.

The Question of the Proportionality Bar

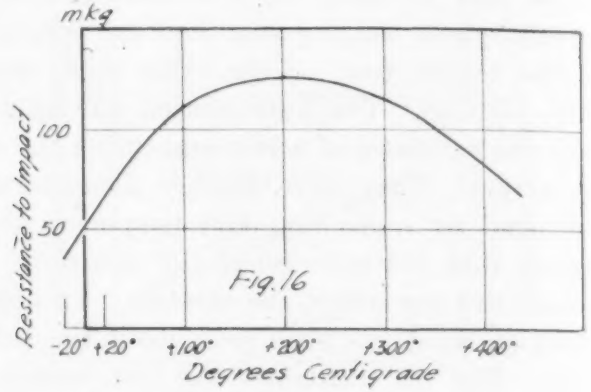
The technical testing of material often requires the use of proportionality bars; different considerations make it appear desirable to reduce the dimensions of the test bar. In so far as this reduction is carried out proportionally, it has proved to be quite admissible for the tensile test. For the notched-bar impact test, however, the use of proportionality bars mostly gave results which could not be properly recorded. These conditions have been investigated by Stribeck in a special paper[5] with the aid of a large number of test series. The course of analyzing Stribeck's material from the point of view of the new knowledge and completing it by appropriate further tests naturally suggested itself.

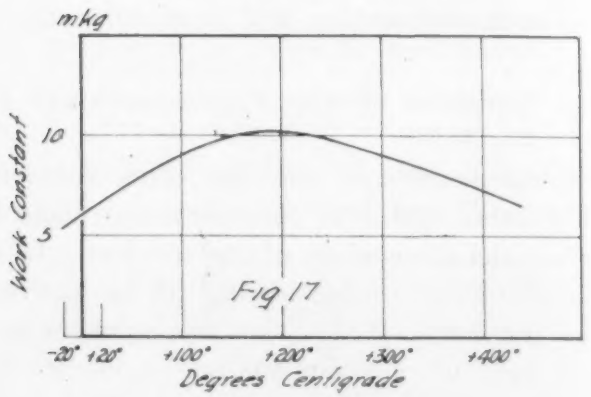
Stribeck's Test

Comparative tests were made with bars of brittle and of tough steels having a cross section of 3 × 3 centimeters and of 1 × 1 centimeters. In the case of the 3-centimeter bars, the diameter of the notch bore was 6 millimeters, and in the case of the 1-centimeter bars, 2 millimeters. The notches were tangent to the center of the bar. Most of the 1-centimeter test pieces were prepared

[5]Stribeck: Die Kerbschlagprobe und das Aehnlichkeitsgesetz. Stahl und Eisen 35 (1915), pp. 392-396.

from fragments of the 3-centimeter test pieces. The 3-centimeter test pieces were ruptured by the 190 kilogram hammer, the 1-





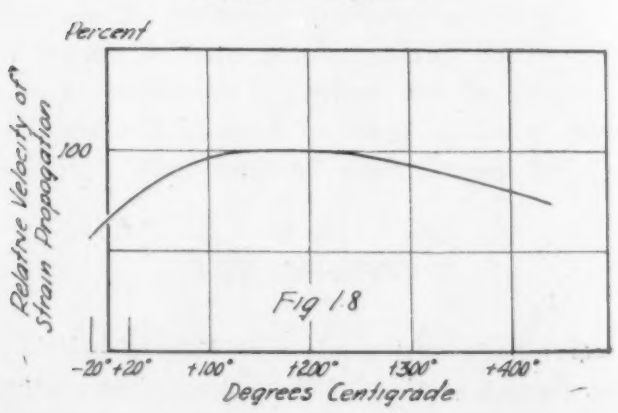


Fig. 16—Curve Showing Influence of Test Temperature on Resilence.
Fig. 17—Curve Showing Influence of Test Temperature on Work-Constant.
Fig. 18—Curve Showing Influence of Test Temperature on Velocity of Strain Propagation.

centimeter test pieces by the 10 kilogram hammer. The distance between the supports was 120 millimeters for the 3-centimeter test pieces, and 40 millimeters for the 1-centimeter test pieces.

A behaviour conforming to a fixed law is only to be expected from the tough steels B2 to E, which have been placed by Stribeck in one group, and the results of which will, therefore, be dealt with in the first place. A first point to be considered in comparing the results obtained is the fact that in one series of test pieces the

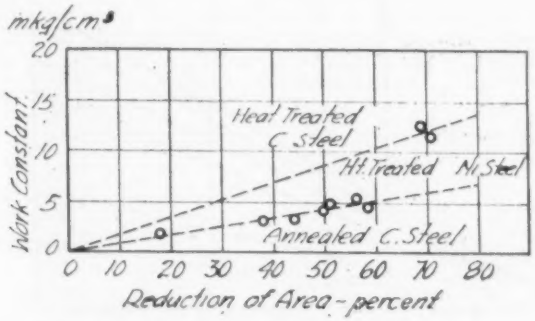


Fig. 19—Curves Showing the Relation Between Reduction of Area and Work-Constant.

diameter of the bore of the notch bar was 6 millimeters, and in the other 2 millimeters. The effect of the notch consists essentially in limiting the deformation of the material to a very confined volume, the spaces adjoining this part being stiffened even to unyieldingness by the adjacent material. By choosing the notch diameter accordingly we are enabled to "tighten" or "loosen" the form-changing "brake." To express this in the terms of the new insight: The inclination of the maximum value line of the working-volume depends on the form of the notch. Fig. 20 is a reproduction of the corresponding diagram from the paper already referred to: "Zur Gesetzmässigkeit der Kerbschlagprobe." The diagram shows the relation between the V-maximum value lines of the strained volume for notch diameters at the bottom of the notch of ranging from 1 millimeter to 13 millimeters for standard German test bars of different widths. It shows that the ratio of the working volume figures for 6- and 2-millimeter bores is approximately 2.1. It is necessary to divide the impact results obtained by Stribeck with the "large" bar by this value, in order to allow for the different amount of stiffening of the material in the two kinds of bars.

Stribeck gives in his tables both the mean ratio of the impact energy of the two kinds of bars and the individual notch toughness values. (Table V of this paper.)

On the basis of the "square of the size" ratio (adopted by international agreement at Copenhagen, in 1909), one would expect a ratio of 9:1 for the impact energy of the two bars. Instead

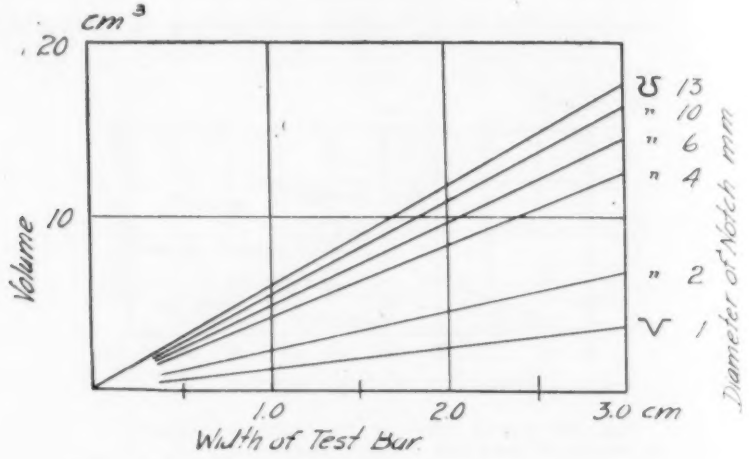


Fig. 20—Strained Volume Maxima Curves Versus Width of Test Bar for Various Notch Diameters.

of this, Stribeck found the ratio to be as 19:1. But if we reduce this ratio by the stiffening coefficient 2.1, we actually obtain the value 9 as the ratio of the impact energy of the large bar to that of the bar of 9 times smaller cross section.

For the individual notch toughness values referred to the cross section area Stribeck found higher values for the large bar than for the small one. Table V contains in column 2 the notch toughnesses of the large bar measured by Stribeck for groups B2 to E. Column 3 gives the result of the reduction of these values by means of the stiffening coefficient 2.1. Column 4 shows, for comparison, the Stribeck values for the small bar. The conformity of columns 3 and 4 is, considering the error limits, a complete one.

New Tests

Test pieces of square impact cross section, with sides increasing gradually from 1 to 3 centimeters in length, were made from carbon steel containing 0.30 per cent carbon, whose working-volume curve corresponding to the standard velocity deviated from the maximum value curve in the case of test piece of greater

Table V

Material	3 centimeter test pieces: Notch toughness with 6-millimeter notch	3 centimeter test pieces: The same reduced to 2-millimeter notch	1 centimeter test pieces: Notch toughness with 2-millimeter notch
1	2	3	4
B2	15.1	7.2	6.70
	13.7	6.5	6.49
	14.3	6.8	6.74
	13.4	6.4	6.73
	13.8	6.59	6.76
	13.9	6.62	6.76
	Mean 14.0	6.66	6.70
C	20.2	9.6	11.1
	21.6	10.6	11.9
	21.8	10.8	11.1
	...	...	10.9
	...	...	10.7
	Mean 21.2	10.1	11.1
D	25.2	12.0	12.45
	...	...	12.60
	Mean 25.2	12.0	12.53
E	29.9	14.2	14.4
	...	...	14.3
	Mean 29.9	14.2	14.35

width. All test pieces had the same notch with 4 millimeter diameter of bore and were ruptured on the same support and with the same velocity.

Fig. 21 illustrates the relation existing between the amount of the impact energy and the size of the cross section; a proportionality lying within the limits of error is apparent. To this proportionality of cross section and impact work corresponds the uniformity lying within the error limits, of the notch toughness in kilograms per cubic centimeter obtained with bars of different size, as given in column 3 of Table VI.

The reduced results of the Stribeck test group and those of the more recent tests demonstrate the validity under certain conditions of the rule adopted at Copenhagen in 1909, according to which the impact work increases as the square of the size ratio. The first condition is, to choose a side ratio of the bars with which the material, at the striking velocity employed, satisfies the maximum working-volume line. As a second condition, the notch, in other terms, the degree of stiffening, must be identical for all the

Table VI

Cross section areas	Impact energy (resilience) kilograms	Notch toughness kilograms per cubic centimeter
1.0×1.0=1.0 sq. cm.	15.7	15.7
1.2×1.2=1.44 sq. cm.	23.4	16.3
1.4×1.4=1.96 sq. cm.	36.8	18.8
1.6×1.6=2.56 sq. cm.	46.1	18.0
1.8×1.8=3.24 sq. cm.	38.7	11.9
2.0×2.0=4.0 sq. cm.	55.3	13.8
2.2×2.2=4.84 sq. cm.	71.4	14.6
2.4×2.4=5.76 sq. cm.	95.0	16.1
2.6×2.6=6.76 sq. cm.	96.7	14.7
2.8×2.8=7.84 sq. cm.	125.2	16.0
3.0×3.0=9.0 sq. cm.	149.3	16.5

bars. Under these conditions, it is evidently possible in technical material testing to use proportionality bars in the notch impact test also. Other points which must be kept in view in this connection will be discussed on the conclusion of further tests that are now being carried out.

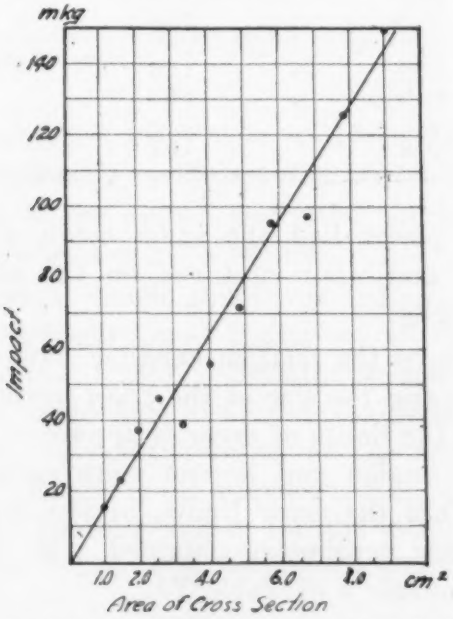


Fig. 21—Relation of Resilience to Cross Section Area with Notched Impact Test Bars of Square Impact Cross-Section.

As to the steels placed by Stribeck in groups AI′ to BI, they did not comply with the first condition mentioned above. They were materials from which test pieces of the chosen cross section (b = 2a) undoubtedly do not satisfy the maximum working volum:

line. If, with such materials, it is desired to use proportionality bars, a side ratio (b = a) should be chosen, in order to be sure that the test piece satisfies condition 1.

Recapitulation

1. The notch impact test is a working test. By resolving the impact test results into:

a The amount of work absorbed by the unit volume, and,

b The velocity of strain propagation and by separately evaluating these two factors, which must be regarded as fundamental properties of the material, the notch impact test affords a possibility of strictly characterizing the material and of choosing it according to the requirements of the designer.

c The work-constant of the unit volume is found by dividing the impact energy of a test piece by the number of the volume units participating in the absorption of the energy. Practically, the simplest way is to divide an impact energy value lying on the line of proportionality by the maximum working-volume value fixed by the law, for instance by dividing the resilience of a test piece with square impact cross section (1.5 × 1.5 centimeters) by the volume value 6.3 cubic centimeters.

d The measure of the propagation velocity is the limiting striking velocity, that is, the velocity at which the working-volume values begin to drop below the maximum values, according to the law, and the resilience deviates from the proportionality line. A practically sufficient idea of the speed of a material is obtained by fracturing a square (1.5 × 1.5 centimeters impact cross section) test piece and one of double the width (3 × 1.5 centimeters), and comparing the results, the figures so obtained being used to calculate not only the work-constant, but the velocity of propagation of the metal as well.

As an auxiliary for the "abridged method," tables can be used instead of calculations.

2. Being properties of the material, the work-constant of the unit volume and the velocity of propagation are dependent on the treatment that the material has been subjected to.

A heat treatment which does not change the nature of the microstructure, but influences only its size, influences above all

the velocity of propagation of the material; the velocity of propagation decreasing with increasing size of the grain.

A heat treatment which changes not only the size but the nature of the microstructure also, likewise, changes the amount of the work that can be absorbed per unit volume.

3. Work-constant and the propagation velocity are influenced both in the same way by the temperature at which the notch impact test is carried out.

4. The work-constant of the unit volume, determined by the notch impact test, bears a definite relation to the contraction of area measured in the tensile test.

5. The preliminary for the use of proportionality bars in the notch impact test is, that the bars be given a side ratio (b:a), with which the steel satisfies the maximum working-volume line, when using the respective impact velocity. Furthermore, the notch must be identical for all proportionality bars.

CAUSES AND CONTROLLING FACTORS IN THE CORROSION OF IRON AND STEEL

By W. P. Wood

Abstract

The importance of corrosion and early interest in its phenomena are briefly discussed. The acid and electrolytic theories are compared and a review of the work leading up to the substantiation of the latter is made. It is pointed out that the fundamental reactions in corrosion of iron and steel are fairly simple, the variations which are observed being largely due to variations in attendant conditions. The inaccuracy of acid tests is emphasized. The controlling factors of corrosion are listed and their effects and importance discussed. A brief review of the author's work in connection with the effect of light upon corrosion of iron is made at the end of the paper.

THE subject of corrosion has become, during the last five years, one of the most important and vital considerations confronting those industries whose operations involve the use of large quantities of metals. When viewed in its entirety, the subject is so vast and the attendant conditions so variable, that one almost despairs of the ultimate solution of the manifold problems involved. Up to a short time ago, the greatest interest had been exhibited in the corrosion of the ferrous metals. This was natural, since they are used in notably larger quantities than any one group of non-ferrous metals. Of late, however, there is a tendency in corrosion study to consider the problems met with in the non-ferrous field as well, and this tendency will doubtless be more marked as time goes on. Since the group before which this paper is being presented, is made up of those primarily interested in iron and steel, the present discussion will be confined to the corrosion of the ferrous metals.

It is a curious thing that the importance of corrosion as an industrial problem, was not recognized years ago, but the main reason for this is well stated in an editorial paragraph in a recent issue of *Chemical and Metallurgical Engineering*.

"Corrosion's wastage is often neglected because it does not

A paper presented before the Detroit chapter of the Society. The author, W. P. Wood, member A. S. S. T., is assistant professor of metallurgical engineering, University of Michigan, Ann Arbor, Michigan.

appear on a separate ledger account. Its loss is charged to installation, to maintenance and repair, or, as is most often the case, is totally obscured in a blanket depreciation figure, mysteriously arrived at and sacredly guarded against analysis and revision. The neglect of corrosion was particularly true in the days when replacement and repair costs were relatively small. Then it scarcely mattered that depreciation was rapid. But with the increase in manufacturing efficiency, with the tendency toward standardization of process and machinery, the margin of profit has grown steadily less. Replacement and installation costs have assumed a greater importance. In many instances, corrosion resistance has spelled the difference between profit and loss.''

The tendency in the past has been to select the material which was judged best adapted for a particular purpose (often at increased cost) without focusing attention to the underlying reasons for the corrosion. Fortunately, the opposite attitude is largely found at the present time and there is little doubt that the next few years will record notable advances in our knowledge of the mechanism of corrosion, as well as methods of inhibiting or preventing it.

From an historical standpoint, it is interesting to recall that a few of our most familiar chemical conceptions were originally the result of an interest aroused by the rusting or corroding of metals. As early as 1630, it was noted by a French physician, Jean Rey, that metals became heavier when they rusted. Similar observations were made by other investigators and the conclusion reached by all was that the air had something to do with the increase in weight upon rusting. It remained for Lavoisier, however, in 1774, to demonstrate that part of the air disappeared when a metal corroded and that oxygen was the element which disappeared. It furnishes a strange anomoly that a hundred years after Lavoisier's work, when a theory of corrosion was stated, the function of oxygen was scarcely considered and it is only within the last few years that its importance as an influencing factor has been appreciated.

It is not the purpose of this paper to cite and describe a large number of specific or peculiar cases of corrosion and then attempt to explain them, but it is the purpose to present the best views with regard to the fundamental reactions of the corrosion of iron

and the factors which control the reactions, once started. Examples and results of investigations will, of necessity, be introduced to illustrate points in connection with the above mentioned purpose.

Corrosion Phenomena

Corrosion phenomena divide themselves naturally into two classes: those observed when metals are exposed to the action of the atmosphere, and those observed when metals are immersed, continuously or intermittently, in various kinds of liquids. In the present discussion, we shall confine ourselves to the first class and that portion of the second which is concerned with results of immersion in water, with a few observations upon the behavior of iron and steel in the presence of dilute solutions of acids and bases.

While it has been stated that atmospheric corrosion is somewhat different than that produced by immersion in natural waters it should be pointed out that the difference is largely one of degree and a slight variation in the character of the final products. The fundamental reactions are without doubt the same, for we find that the presence of moisture is an essential condition in all common cases of atmospheric corrosion.

Theories of Corrosion

Several theories of corrosion have been advanced during the last fifty years, but most of them have been discarded for the more rational electrolytic theory, which is the one accepted by the great majority of investigators at the present time. The most important theory opposed to the electrolytic theory, was the so-called acid theory, and there is little doubt that this theory has still some adherents, but they, at least, are not so complacently confident as was the case a few years ago. If one will turn to any text book of chemistry which was in use fifteen to twenty years ago, he will almost invariably find that iron rust was considered to be a mysterious mixture of hydrates, oxides, and carbonates, mostly carbonates. This view was the result of a tacit acceptance of the acid theory which was much in vogue at that time.

Acid Theory

Since the acid theory was the first one of the two to be pro-

posed, we shall first consider it here. This theory states that the presence of an acid is necessary for corrosion of iron to start. In the case of corrosion by the atmosphere or by immersion in natural waters, the main one which is present is carbonic acid (CO_2). It is thus easily seen why most of the subsequent discussions hinged around the question of whether or not CO_2 was necessary for corrosion to proceed. Many investigations were carried out to settle this troublesome point.

The acid theory states that the simple corrosion of iron proceeds through the following reactions:

$$2Fe + 2H_2CO_3 \rightleftarrows 2FeCO_3 + 2H_2$$

$$4FeCO_3 + 10H_2O + O_2 \rightleftarrows 4Fe(OH)_3 + 4H_2CO_3$$

It is seen that the corrosion of iron would be a cyclical phenomenon, a very small amount of acid being required to corrode a large amount of iron. Reasoning further, the corrosion of iron might be much inhibited or even prevented by the presence of a small amount of a base. This is actually the case and for a considerable time was cited as one of the proofs of the acid theory. This phenomenon, however, is equally well explained by the electrolytic theory. It will be further seen that oxygen is required for a completion of the cycle but the importance of this fact was lost sight of in the vigorous campaign to prove that the presence of an acid radicle was necessary.

One of the active adherents of the acid theory was Moody,[1] who believed that he thoroughly demonstrated that the presence of CO_2 was necessary for corrosion to begin. His experiments were repeated by Dunstan,[2] who was unable to duplicate Moody's results and concluded that CO_2 was not necessary. Dunstan's work was so carefully done that it seems really to prove that CO_2 plays an almost negligible role in the corrosion of iron.

Probably the most conclusive work along this line is an experiment which was carried out by Cushman and Gardner,[3] which is briefly described by Wilson[4] in his little volume entitled "The

[1]G. T. Moody, *Transactions*, Chemical Society, 89, 720 (1906).

[2]Dunstan, *Proceedings*, Chemical Society, 23, 63, (1907).

[3]Cushman and Gardner, "Corrosion and Preservation of Iron and Steel," p. 373 (1910).

[4]L. C. Wilson, "The Corrosion of Iron," p. 178 (1915).

Corrosion of Iron." The following description is quoted from Mr. Wilson's book:

"Two Jena glass flasks were nearly filled with freshly distilled water and boiled vigorously one-half hour, at the end of which time, bright, polished strips of steel and charcoal iron were slipped into the flasks and the boiling continued a few minutes longer. The flasks were then completely filled with boiled water and every trace of air removed. No rust appeared on the strips, even when they were kept indefinitely in this boiled water. Pure oxygen was then freed from every trace of carbonic acid and passed into the flasks, whereupon rust formed on the bright pieces in about five minutes and was heavy in an hour. The action seemed to take place in patches, having the appearance of a pattern corresponding to the physical structure of the metal. This experiment was also made using phenolphthalein, a substance which shows the presence of exceedingly small amounts of acid or alkali, and invariably a pink color developed, showing that no carbonic acid was present. . . .

"The experiment was also tried of substituting pure carbonic acid gas, perfectly free from oxygen in place of the oxygen used in the above tests. Under these circumstances no apparent action took place, even after several hours, although no doubt a slight amount of iron went into solution as the carbonate. When pure oxygen was allowed to enter and mingle with the carbonic acid gas, rusting began very shortly, a characteristic blue-green color which always accompanies the early formation of rust in the presence of carbonic acid being noticed. In normal rusting in the air, this color is not to be seen."

Some doubt might be expressed as to the possibility of boiling out all traces of carbonic acid from the water in the flask in the experiments just described. An answer to this may be found by quoting a paragraph from Whitney,[5] who first stated the electrolytic theory. "Assuming the laws of Henry and Dalton to apply to the solubility of carbonic acid gas in water, also that the solubility of the pure gas under ordinary pressure is one volume for one volume of water (which is correct at 15 degrees Cent.) and, finally, that the normal content of carbonic acid in the atmosphere is 2 parts in 10,000 by volume, we should expect water in equilibrium with air containing this concentration of carbonic acid to

[5] Whitney, *Journal*, American Chemical Society, 25, 397 (1903).

contain 0.0002 volume CO_2 per volume of water. This corresponds to a concentration of the CO_2 equal to 0.0001 volumes per liter, or 0.00002 normal. From the dissociation constant 3030 x 10^{-10} determined by Walker, it follows that the first hydrogen of the acid is 16 per cent dissociated at this concentration. From this it follows that 10,000,000 liters of water containing CO_2 in equilibrium with ordinary air at 15 degrees Cent. contains 16 grams of hydrogen ions or only 16 times as many as perfectly pure water contains. At the boiling temperature the CO_2 dissolved would probably yield a concentration of hydrogen ions even less than in pure water, for not only is the solubility of the gas greatly diminished, but the dissociation of water is greatly increased by rise of temperature. Moreover, the distilling water would rapidly reduce the concentration of any carbonic acid capable of dissolving in water at 100 degrees Cent."

Having disposed of the question of whether or not CO_2 is necessary for the corrosion of iron to proceed, the field is now clear for a consideration of the electrolytic theory.

Electrolytic Theory

The electrolytic theory involves primarily the partial solution of iron in water resulting in the formation of soluble ferrous hydroxide. It was the demonstration of this point which proved somewhat difficult to the early proponents of the electrolytic theory. Cushman and Gardner[6] finally carried out a series of experiments which demonstrated quite satisfactorily that a small amount of iron will be dissolved in pure water, oxygen and acid radicles being absent.

Probably the best exposition of the electrolytic theory has been made by Wilson,[7] from whose article the following discussion is abstracted. As stated by him, the fundamental reaction in the corrosion of iron is:

$$Fe + 2H^{x} \rightleftarrows Fe^{xx} + 2H \qquad (1)$$

The broad interpretation of this reaction is that the presence of the hydrogen ion is necessary for incipient corrosion. One of the products of the above reaction is hydrogen, which will collect at the reaction point as a polarizing film. Unless this film of hydrogen

[6] Cushman and Gardner, "Corrosion and Preservation of Iron and Steel," p. 373 (1910).

[7] R. E. Wilson, *Industrial and Engineering Chemistry*, 15, 2, 127 (1923).

is continuously removed the reaction will soon cease. The removal of the hydrogen may be accomplished by one or both of the following reactions:

$$2H + \tfrac{1}{2}O_2 \rightleftarrows H_2O \qquad (2)$$

$$2H \rightleftarrows H_2 \text{ (gas)} \qquad (3)$$

It has been observed that in the corrosion of iron by natural waters the amount of hydrogen evolved is almost negligible as compared to the amount of oxygen consumed. It, therefore, follows that reaction (3) is responsible for the removal of only the slightest amount of hydrogen, and that reaction (1) and (2) determine the rate of corrosion in natural waters. In the case of corrosion of iron in neutral or alkaline solutions there is a secondary reaction involving the oxidation of $Fe(OH)_2$ to $Fe(OH)_3$. This reaction is not considered important as influencing the corrosion rate. As the alkalinity of a solution increases the hydrogen ion concentration decreases until a point is reached where reaction 2 ceases to be a controlling factor and reaction 1 becomes the determining factor. The rate of corrosion will, therefore, be much inhibited but not necessarily stopped. It is well known that the presence of a small amount of base will very noticeably decrease the corrosion rate of iron.

Turning to the situation where corrosion begins to take place in increasingly acid solutions, it is noted that reaction (3) becomes the controlling factor as soon as any appreciable evolution of hydrogen occurs. As affecting the rate of reaction (3) the hydrogen overvoltage of the metal will be the most important consideration. This in turn will be markedly affected by the presence of any impurities in the metal, and many reported differences in corrosion rates of various metals have been, without question, due to this factor. Wilson rightly points out the fallacy of comparing the corrosion resistance of various metals on the basis of acid tests.

Factors Influencing Corrosion

Accepting the fundamental reactions in corrosion to be those which have been previously stated, it next becomes necessary to consider the factors which influence the reactions at the time of their appearance and during their subsequent course. A list of these factors follows:

1. Solution potential of the metal

2. Concentration of metal ions in the solution
3. Hydrogen ion concentration of the solution
4. Rate of removal of polarizing film of hydrogen
5. Hydrogen overvoltage of the metal
6. Action of protective films
7. Velocity of movement of the solution
8. Temperature
9. Solubility of oxygen in the solution
10. Humidity of the air
11. Depth of immersion
12. Viscosity of solution
13. Effect of different metals in contact
14. Condition of metal surface
15. Light.

According to Speller,[8] these factors are conveniently divided into two classes, the first four representing the so-called primary factors or factors necessary for initial corrosion, the rest representing factors which influence the ultimate rate of corrosion.

In the light of the previous discussion of the mechanism of the electrolytic conception of corrosion, the importance of factors 1, 3, and 4 is easily recognized. Factor 2 might not be at once appreciated but it is evident that if there is a notable quantity of ferrous ions present in a solution which is in contact with iron, there will be a somewhat decreased tendency for the metal to pass into solution. Roughly speaking, it might be considered as a back pressure working against the solution potential of the metal.

As has been intimated previously, the effect of hydrogen overvoltage will be of greatest importance in corrosion by dilute acid solutions. In corrosion by natural waters, however, its importance would be practically nil, except possibly in the case of dissimilar metals in contact in the presence of water.

The importance of film production and influence in connection with the inhibition of corrosion has been only recently appreciated. We are indebted to Speller[9] and Bancroft[10] for emphasizing this factor. Some extremely useful aspects of this factor were brought

[8]Speller, Film Protection as a Factor in Corrosion. Preprint of paper delivered at October, 1924, meeting of American Electrochemical Society.

[9]Speller, *Journal*, Franklin Institute, 193, 519 (1922).

[10]Bancroft, *Proceedings*, American Society for Testing Materials, 22, II (1922).

out in a recent paper by Speller,[11] who has been working on the corrosion of iron in closed water systems for several years. It has, perhaps, been insufficiently emphasized that oxygen, through its depolarizing action according to reaction (2), is the most important single factor in corrosion of iron in natural waters. The removal or neutralization of oxygen is, therefore, one of the most important considerations in preventing or inhibiting such corrosion. One of the commercial means of accomplishing this is by the use of a so-called "deactivator," which allows the dissolved oxygen to be fixed by reacting on large replaceable surfaces of iron, before the water passes into the main system. Such installations are most useful for large service, and Speller predicts that the smaller ones may be taken care of by the use of protective films.

To be in any measure a protection, a film must be of such a nature that the solution is not allowed to come into contact with the metal, nor oxygen permitted to diffuse to and from the surface of the metal. Some waters form natural protective coatings. The author recently examined a section of pipe which had been in service for thirteen years. It contained a thin hard scale which had preserved the inner surface of the pipe in almost the condition which had obtained at the time of installation. The scale was largely composed of calcium sulphate. There is a limit to the desirability of such scale deposits, since they continue to increase in thickness and may in time completely choke the pipe.

It has been noted that copper-bearing steel resists atmospheric corrosion to a greater degree than ordinary carbon steel, while in corrosion by immersion in water it is no better and, indeed, in some cases has seemed to be inferior. The protection of this steel against atmospheric corrosion seems to be due to the presence of a dense hard coating of rust, the formation of which is assisted by the copper. While the fundamental reactions in both atmospheric and underwater corrosion are probably the same, the controlling conditions may be enough different to widely vary the amount of metal consumed by the action.

Probably the most interesting recent development in connection with film formation is the deliberate production of films by the addition of soluble silicates to the water. The colloidal SiO_2 which is formed combines with ferric hydroxide in building up a

[11] Loc. cit.

dense and adherent coating which furnishes notable resistance to corrosion. Fig. 1 is a chart reproduced from Speller's paper,[12] which illustrates the effect upon corrosion rate of Pittsburgh water by additions of sodium silicate.

This whole subject of film protection is bound to receive greater and greater attention as the practice of installing industrial and

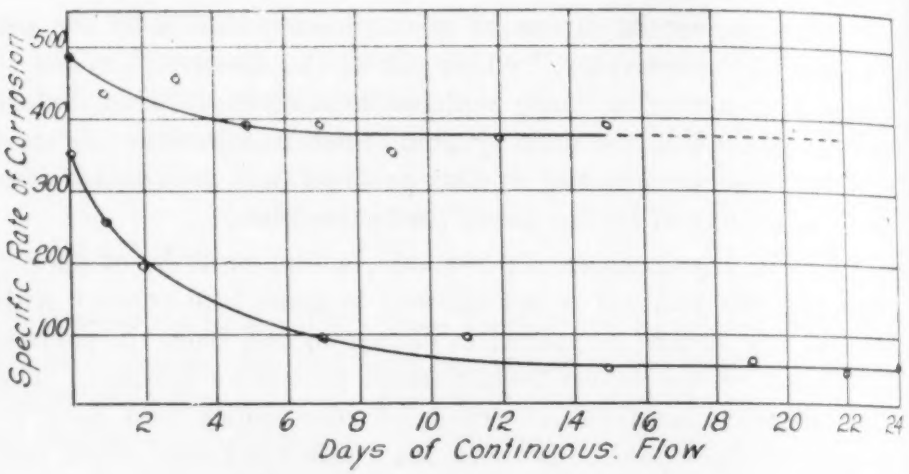


Fig. 1—Effect Upon Corrosion Rate of Pittsburgh Water Flowing Through Clean Black Steel Pipe at a Temperature of 110 degrees Fahr. (43 degrees Cent.). The Upper Curve—Raw Pittsburgh Water. The Lower Curve—Pittsburgh Water plus Sodium Silicate.

municipal water softening plants increases, for it has been noted in many such cases that as the troubles from the use of hard water begin to disappear, difficulties from corrosion make their appearance.

When corrosion is taking place in moving water, it is manifest that the velocity of the water will exert some effect upon the reaction. Heyn and Bauer,[13] and Friend[14] report that corrosion under such circumstances proceeds at a rate directly proportional to the velocity of the liquid up to a certain point and after that point is reached, exhibits a marked decrease in rate. Speller[15] has also studied this phase of the subject and his results do not check those of the above mentioned investigators. Fig. 2 is a reproduction of one of Speller's charts which conveys the general trend of his results. The specific rate of corrosion which is used in this

[12]Loc. cit.

[13]Heyn and Bauer, "Mitt. König. Material Prüfungsamt," Berlin, 28, 62 (1910).

[14]Friend, "The Corrosion of Iron," Carnegie Scholarship Memoirs, 11 (1922).

[15]Speller, *Industrial and Engineering Chemistry*, 15, 2, 134 (1923).

chart is obtained from a formula suggested by Wilson[16] and is equal to milligrams loss per square centimeter per year per cubic centimeter of oxygen in one liter of water. The factor of temperature is also included in this chart which is a rather happy occur-

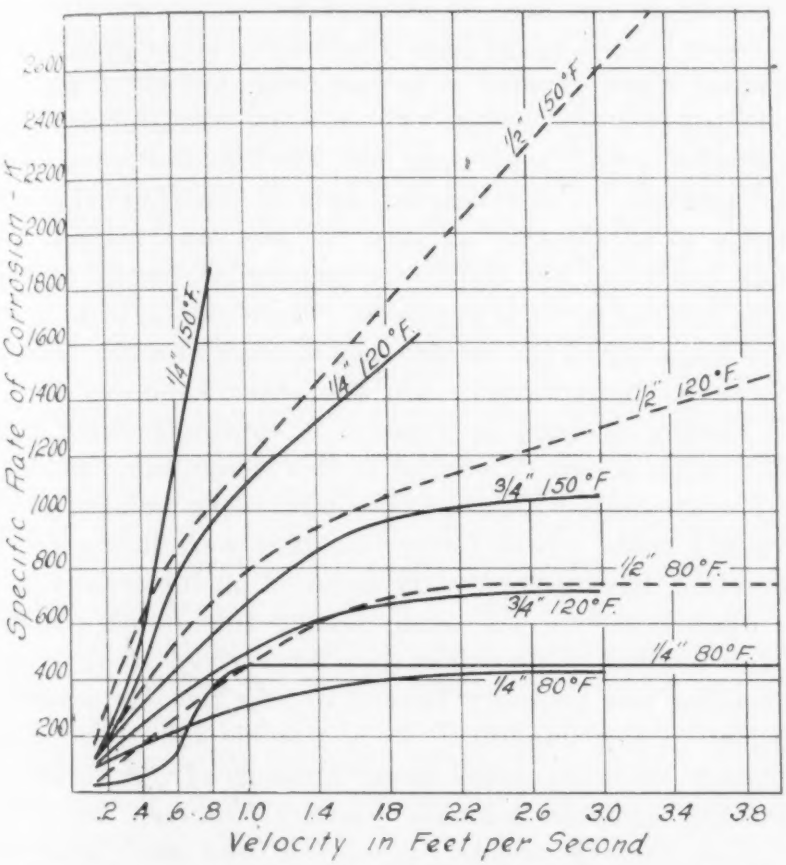


Fig. 2—Corrosion in Pipes. Comparative Curves Showing Specific Rate of Corrosion Versus Velocity. The Pipe-Sizes are shown on each Curve.

rence as far as the present discussion is concerned, for it gives concrete evidence of the usual accelerating effect which increase of temperature causes in any underwater corrosion. Briefly stated, the chart shows no diminution of corrosion rate with velocity in the pipes tested, but rather, indicates that at lower temperatures, the corrosion rate becomes constant after a certain velocity is attained and at higher temperatures, shows a rapidly accelerating rate.

Remembering the importance of oxygen as a controlling factor of corrosion, it is not necessary to enlarge upon the importance

[16]Loc. cit.

of the oxygen solubility of the corroding medium. It has been shown, that other factors being non-effective, corrosion drops almost to zero in the absence of oxygen.

The importance of humidity of the air as a controlling factor lies largely in the field of atmospheric corrosion, although it is conceivable that it might have a noticeable effect upon the oxygen content of water exposed to the air, and thus effect the corrosion rate of metal in the water. There is an unmistakable difference in corrosive attack upon iron and steel in dry climates and in humid climates. The classic example of the iron pillar at Delhi in India is an instance of this. It has been claimed that the extreme purity of the metal was responsible for its resistance to rusting, but the metal is not pure. There can be little doubt that the low humidity of the climate has, in large measure, been responsible for its preservation. On the other hand we witness the rapid rusting of steel in regions of constantly high humidity. Speller[17] cites a case of interest in this connection. In examining some French steels which had been left on the Isthmus of Panama for twenty years, it was found that they were in a good state of preservation, having apparently acquired an impervious rust coating. Upon removing this oxide coating these steels rusted badly in a few months. The explanation advanced is that the original rust coating was probably formed during the dry season, under conditions of low humidity. It is possible that coatings formed under such conditions carry larger amounts of pure oxide. These observations have considerable practical interest, for they seem to indicate that the whole life of iron and steel when exposed to atmospheric action, may be vitally affected by the conditions obtaining at the time of initial exposure.

When metals are immersed in various corroding media, it has been observed that the rate of corrosive attack is noticeably decreased as the depth of immersion is increased. There are at least three possible contributing factors here,—rate of oxygen diffusion pressure, and light. In perfectly quiet water the oxygen content is probably not as high at considerable depths as it is at the surface, but such a situation would probably not be the rule. The effect of increased pressure at greater depths upon the corrosion reactions is a subject in connection with which there is little or no

[17]Loc. cit.

information. The possible effect of light will be discussed in a later paragraph. The variation in corrosion with increase in depth is not large, so that the importance of this factor from a practical standpoint is very slight.

The corrosion rate of iron is decreased as the viscosity of the medium increases, other things being equal. The effect is mainly brought about by slowing up the diffusion of oxygen, provided the corrosion is taking place in the region where the oxygen concentration is the controlling factor. The effect would also be noticed to some extent in corrosion by dilute acid and alkaline solutions, although to not as great a degree, perhaps. The limit approached in application of this factor is the point where the material becomes viscous enough to actually form a protective film. Inert, extremely viscous materials form one of our most useful types of industrial corrosion preventives, as is evidenced by the use of such materials as greases, etc. The whole action of such coatings, or any coating, for that matter, is to prevent the contact of oxygen and moisture with the metal.

One of the most familiar and interesting of corrosion factors is the effect brought about by dissimilar metals in contact in the presence of the corroding medium. Walker[18] and Wilson[19] have discussed very completely the theoretical aspects of this phase of corrosion. This effect is brought about primarily by the relative positions of the metals in the electromotive series. This is a series of the metals, including hydrogen (Table I), arranged in descending order of their tendency to pass into solution, or, in other words,

Table I
Electromotive Series of the Metals

1. Potassium	6. Magnesium	11. Iron	16. Lead	21. Antimony
2. Sodium	7. Aluminum	12. Thallium	17. Hydrogen	22. Mercury
3. Barium	8. Manganese	13. Cobalt	18. Copper	23. Silver
4. Strontium	9. Zinc	14. Nickel	19. Arsenic	24. Platinum
5. Calcium	10. Cadmium	15. Tin	20. Bismuth	25. Gold

into the ionic condition. Each member of the list in the free state will displace ions of any metal following it in the list, when placed in a solution of one of the latter's salts. A familiar example is the precipitation of copper upon iron when iron is placed in a solution

[18] Walker, *Mechanical Engineering*, 23, 677 (1909).

[19] Loc. cit.

of copper sulphate. Any member of the list is spoken of as being electronegative to any metal following it and electropositive to any metal preceding it.

A glance at the electromotive series explains one reason why zinc is used as a protective coating for iron. When both are exposed to water the zinc tends to go into solution and suppresses, as it were, the tendency of the iron to dissolve. The second reason that zinc is used as a protective coating is that zinc in and of itself is quite resistant to corrosion, provided there is no contact with more electropositive metals in the same solution. The reason for this individual resistance of zinc to corrosion is possibly in its hydrogen overvoltage.

An intelligent application of the information obtained from a consideration of the electromotive series of the metals will often effect an important decrease in the corrosion observed in various types of installations. An interesting instance of this came to the author's attention last year. An almost intolerable condition had been present in a municipal water system on account of corrosion of domestic meters, particularly the gear trains. In some cases the teeth on the gears had entirely disappeared. An investigation of a large number of such failures revealed the fact that the corrosion was practically confined to all-bronze meters. Analysis of the water showed an unusually large amount of bicarbonates and some dissolved oxygen. The corrosion product upon all the gear trains was practically completely made up of basic copper carbonate, which proved that the bicarbonates and the oxygen were largely responsible for the corrosion observed. During the examination of various types of meters which had been used, remarkably good service was found to have been given by a meter which was fitted with a cast iron body, the cast iron body being in metallic contact with the bronze gear train. In some instances these meters had given uninterrupted service for from twelve to seventeen years, while many all-bronze meters had been replaced after a few months' service. The iron was apparently electronegative to the bronze, as might possibly be predicted from the positions of copper and tin in the electromotive series, and had thus preserved the bronze gear trains from serious attack.

Too broad an application of the electromotive series should not be made, for it has been observed that some of the metals have

a bad habit of reversing their polarity under some conditions, and unfortunately, these conditions are not always known, nor can they with certainty be predicted. Recently a most peculiar case of corrosion was brought to the author's attention. It was that of the corrosion of some large chromium steel balls which had been inadvertently mixed with ordinary steels balls as bearings for a rotating gas producer. The chromium steel balls carried 1.35 per cent of carbon and 1.39 per cent chromium, while the carbon steel balls carried 1.05 per cent carbon. Other primary elements were well within the limits set by specifications. The chromium steel balls were badly pitted while the carbon steel balls showed perfectly smooth surfaces. One would hardly have predicted such a result.

Corrosive action as a rule will be very evenly distributed over a polished surface and the tendency for local action or pitting not so evident. In such a case it may be considered that the condition of the surface will have an inhibitive action upon the corrosive attack. The presence of small areas of oxide, however, may produce a very decided tendency toward pitting, which, of course, may cause an earlier failure than would be the case if the action were uniform over the whole surface. Such small areas of oxide serve to hasten the oxidation of the nascent hydrogen and thus accelerate corrosion at that point.

Investigations concerning the effect of light upon the corrosion of iron and steel have been carried out by Cribb and Arnaud,[20] Friend,[21] and Kimura.[22] The results in each case appear to have been positive, but there has been a question raised each time as to whether or not the results may have been due to differences in temperature. In most of the work reported the light used has been sunlight and in that case it is easily seen that temperature conditions would be difficult to control. In order to obtain more precise results, the author constructed a cabinet, the temperature of which could be held constant by circulating air and water and in this carried out some corrosion experiments, having one section of the cabinet brilliantly lighted by means of a frosted 50 watt electric light and another section completely dark.

[20]Cribb and Arnaud, *Analyst*, 30, 225 (1905).

[21]Friend, "Corrosion of Iron and Steel," p. 289 (1911).

[22]Kimura, *Memoirs* of the College of Science and Engineering of Kyoto University. 5, 253.

The metal used in the tests was open hearth iron having the following analysis:

	Per Cent		Per Cent
Carbon	0.028	Sulphur	0.027
Silicon	0.014	Phosphorus	0.003
Manganese	0.014	Iron	99.914

This metal was obtained in sheets about $\frac{5}{16}$ inch thick and samples were cut to a width of 3.5 centimeters and length of about 5 centimeters. All samples were ground on a 200 M wheel to produce uniform surface conditions, and after being measured carefully were washed in alcohol, dried and weighed. The corroding medium used was distilled water and each sample was supported horizontally on stirrups at equal depths in separate beakers. At intervals of seven days samples were removed, washed, dried and weighed as before. The condensed results of this test will be found in Table II, from which the conclusion seems almost unavoidable that there is some actinic effect in corrosion. This effect is undoubtedly much more pronounced in the case of sunlight.

Table II

Loss in milligrams per square centimeter of open hearth iron exposed to the action of distilled water, in darkness and in the presence of white light. The temperature at no time dropped below 23 degrees Cent. or rose above 25 degrees Cent.

Time of Exposure	14 days	21 days	28 days	35 days
White Light	5.2	7.5	9.7	12.1
Darkness	4.5	6.6	9.3	10.3

One possible instance of variation in corrosion by light may be in the decrease of the action as depth of immersion in water increases. At depths of one hundred feet or more in most bodies of water there is not much light present, and the slower rate of corrosion at these depths may be partly due to this fact.

In the light of what has been said here it is quite evident that there are two methods of attacking the question of rust proofing when the articles are to be exposed to the action of natural waters or the atmosphere. One is to so regulate chemical composition that reaction (1) will not take place, and the second is, to provide some means, usually coatings, which will absolutely prevent the contact of the oxygen carrying water with the iron or steel.

SAMPLE PREPARATION FOR HIGH POWER PHOTOMICROGRAPHY

By R. G. Guthrie

Abstract

This paper discusses a method of preparing specimens for high power photomicrography with which it has been possible to eliminate or reduce to a minimum an amorphous film which usually covers the surface of the specimen before etching, and which usually causes uneven etching.

The author describes a method of polishing wherein a paraffin polishing wheel is used. This paraffin wheel is coated with a soap solution carrying abrasive material. The final polish is obtained with a flannel wheel. The specimen is then etched and re-etched until a satisfactory structure is obtained for high power photomicrography.

This paper also includes photomicrographs showing various structures obtained from specimens of steel under both low and high power magnification ranging from 2300 to 15,500.

Introduction

THE fundamental points to be borne in mind in the taking of high power photomicrographs are few and simple. First, in the order of importance is that of proper and suitable equipment; that is, equipment built to accommodate high power work and not an improvisation. Secondly, the sample must be properly polished and etched. These two factors must be supplemented by absolute cleanliness throughout the entire procedure, from sample preparation to developing and printing the photographs. In this work the operator must have patience, good judgment and aptitude. If this last item is possessed in excess the other points will of necessity follow as a natural consequence.

Altogether too much mystery has enshrouded the taking of high power photomicrographs and too much "hokum," if I may use the expression, has been propagated regarding the great complexity of obtaining such a photomicrograph worthy of considera-

A paper presented before the Winter Sectional Meeting of the Society, January 15 and 16, 1925. The author, R. G. Guthrie, member A. S. S. T., is metallurgist, industrial gas department, Peoples Gas Light and Coke Co., Chicago.

tion. I do not believe that the matter is as complex as it has been made to appear.

Purpose of Paper

This paper will deal briefly but thoroughly with the preparation of metallographic samples for high power photomicrography. It is supplemented by a series of photomicrographs in duplicate, showing the same field under two types of illumination. These photomicrographs will serve to demonstrate the effect of the method of sample preparation and at the same time illustrate the matter of extreme detail versus extreme contrast.

It is apparent that there are two types of photomicrographs, one showing great contrast between the constituents contained in the specimen, and the other showing probably less of this contrast but a great deal more detail, that is, the structure in the latter is much more apparent to one examining the photograph. There are also some peculiar conditions arising from a metallurgical standpoint having to do with the interpretation of both types of photographs.

To very simply go into the matter of sample preparation and attempt to relieve the situation of much of its highly technical detail and mysterious glamor that is sometimes thrown around it, the author will first give the original method that was used in his laboratories and the reasons leading to the evolution of the method that is now being used.

The method consisted mainly of first grinding the sample on a coarse-grained emery wheel, washing, and grinding on a medium-grained emery wheel in a direction at right angles to the previous grinding, rewashing and finally grinding on the finest-grained wheel. The sample was then washed and taken to a canvas-covered disc carrying Turkish emery abrasive in water. This operation removed the scratches from the last grinding wheel. At one time this step was followed by a polishing on a satin-covered disc using tripoli in water, but was discontinued due to its pitting action. The sample was then taken directly to a large aluminum disc covered with a good grade of French flannel for the final polish. The abrasive used was levigated alumina in distilled water and produced a satisfactory polish for low power work.

Upon etching a sample prepared in this manner and examining it under high power magnification it was found that the faster

etching constituent was invariably etched too deeply and the slower etching constituent, possibly not deep enough. This made it difficult to locate a spot on a given sample that was etched exactly right for high power photomicrography. By high power photomicrography is meant magnifications of 2000 diameters and above.

On reviewing the situation, it was evident that the unevenness in etching was due primarily to the unevenness in the ferritic or amorphous film which covered the sample after polishing. This condition may be greatly aggravated simply by polishing too long in one direction on a cloth-covered wheel. It was desired to get a sample that had as even and as thin a ferritic or amorphous film as was possible, as this wiping-out action had a great deal to do with the sample after etching because of the fact that the soft constituent wiped-out and covered the harder constituent so that even after a very weak etch the sample would show a deep structural development when viewed with a high power objective such as the 2-millimeter, oil immersion, 1.40 NA apochromat.

In attempting to determine which step in the operation was responsible for the greatest amount of ferritic or amorphous film, and the author uses these two terms because either one of them may be correct, the final polishing wheel was first investigated. It was found that after using various cloths, such as "kitten's ear" silk broadcloth, billiard table cloth, satin, felt, etc., that about the same results were still obtained in each instance. It was then that the preceding operation was investigated, since it was apparent that wherever a cloth-covered disc was used this ferritic film was sure to appear. Various types of weaves of cloth and even parchment were tried on this emery wheel, following the last grinding wheel. It was concluded that the harder the base and the less the structure, i. e., fabric structure, the less the amorphous film and the more nearly flat and abraded the sample became. This gave a clue that a hard, structureless base might lessen the undesirable film, if not entirely eradicate it.

Working on this plan, the new method was devised. It consisted in using a paraffin-covered brass disc. This disc was prepared by pouring molten paraffin onto a disc, the paraffin being prevented from running off by a band of tin wrapped around the periphery. After solidifying, the disc was placed on the polishing machine and rotated under a straight edge, thus dressing out the surface

evently. Also the paraffin may be smoothed and dressed by using a little benzol on a piece of absorbent cotton, as the benzol is an active solvent for the paraffin. However, after such a treatment the disc must be allowed to regain its natural hardness, since the benzol leaves the surface quite soft, whereas it is imperative that it be hard. In regard to dressing with a straight edge it might be said that the impression of a slight "chatter" left in the paraffin was not found to be undesirable but in reality seemed to increase the effective hardness and also minimize the "seizing" of the sample to the paraffin.

It was then necessary to use the abrasive in some medium that would lubricate the sample from the wheel as well as carry the abrasive. Without reviewing the many different mediums that were tried, it will suffice to say that the most satisfactory so far tried is an ordinary glycerine-base soap in distilled water. These soap solutions may be made of varying viscosities, but the one which seems to give the most satisfaction is of the consistency of an ordinary thin lubricating oil. The abrasive, in the first instance, Turkish emery, is introduced at the start and stock solutions made up for future use. The effect of the glycerine is quite necessary to keep the soap from precipitating out of solution.

The tripoli is made up into solution in exactly the same manner and is used to remove all the scratches left by the Turkish emery. An examination of the sample in process after either of these operations will show the action to be, in the main, a grinding one with very little if any, film development. The structure of the sample can be discerned as peeping out here and there through the scratches.

It may be necessary at this time to say that tripoli is necessary on certain samples as an intermediate step between the Turkish emery and the final polish, whereas on other samples which are not so hard to prepare, this step may be omitted to advantage. It has been found that too long a time on the tripoli wheel has a tendency to pit the sample and hence as much of the work as possible should be done on the Turkish emery wheel. The operator should determine which procedure is best for his own particular sample and conditions.

The final polishing stage consists of using a levigated alumina or magnesium oxide in distilled water on a disc covered with a

good grade of white French flannel. It will be found that a much shorter time will be required on this final wheel, particularly when using levigated magnesium oxide, than in the old method of polish. The magnesium oxide is cheap and the method of levigation quite simple and it is highly advisable for the operator to buy this magnesia of the chemically pure quality and levigate it himself. It is also recommended that distilled water be used throughout all these operations. It is hardly necessary to caution the operator to thoroughly wash his sample as well as his hands between each step. It will prove beneficial if the operator will also take the time to dress off the paraffin wheels from time to time, thereby getting the equivalent of a new wheel each time. The paraffin may be put on the disc as thick as ½ inch, and enough removed in dressing each time to get below the embedded abrasive and dirt. Also the cloth on the final wheel, if changed frequently, will prevent considerable disappointment in the final results. By all means no soap should be allowed to get on this cloth, as its polishing efficiency will thereby be greatly reduced.

Etching

As to etching samples prepared in this way it will be found that the ferritic film will be very much thinner and more even than on samples prepared on cloth wheels throughout, and it is a fact that the structure will etch out very much more quickly. On an ordinary carburized sample which may include the annealed condition, from 4 to 7 seconds in a 2 per cent solution of nitric acid in alcohol, it will be found that the same sample polished by this method will etch out quite satisfactorily in from 2 to 4 seconds in a 1 per cent solution. A precaution in etching for high power work is not to etch too deeply if the maximum detail is to be shown. The reason for this of course is that the maximum detail cannot be shown unless both the depth as well as the resolving power of the objective be used to the fullest degree. If the sample is too deeply etched it will simply show contrast and no detail. It follows that a sample properly etched for high power work will not be efficient for low power work because of the fact that the etch will no doubt be too shallow to show sufficient contrast with the objective used.

This method of polishing also lends itself very well to a

repolishing and reetching, or as it is called progressive etching, since the film developed is so slight that the relief effect is negligible. It follows that to get a perfectly flat structure before the final etch, a surface as nearly flat as possible is necessary. This will cause the desired constituent to stand out after the final etch. It is necessary to strike a balance for each particular sample of the two variables, wiping and etching. This is done by progressively etching and repolishing on the final wheel, each time getting closer to the ideal condition of balance by lessening the wiping action and the etching action. Of course the final etch may be considerably deeper than the previous etch.

Whenever it is necessary to repolish a sample, due to an overetch, it is advisable to go back to the emery in soap on paraffin and not to begin with the tripoli wheel, because in this case the pitting action would be emphasized.

The author does not claim anything original or new for this method of sample preparation either in using the soap solution or the paraffin discs, but merely gives the method employed for the preparation of samples, which method was evolved slowly and in the way previously explained.

Photomicrographs

It might be well to explain the reason for showing the photomicrographs in duplicate. In the first place it was desired to show one set of photomicrographs of a field under plain axial illumination, which gives a perfectly flat field with a maximum of contrast, as compared with those taken with conical illumination, in which the center of the light pencil is stopped out. No attempt was made to obtain beautiful photomicrographs, but instead to obtain a result which would show the fundamental differences between these two types of illumination.

The main point to observe in examining these photomicrographs is that in the flat one, a great deal of contrast is seen, whereas in the other, the main point is extreme detail.

The captions for each of these photomicrographs give the data and adjustments used on the equipment employed (Leitz Micro-Metallograph, model 1924).

It is not necesary to go into the phenomenon of illumination

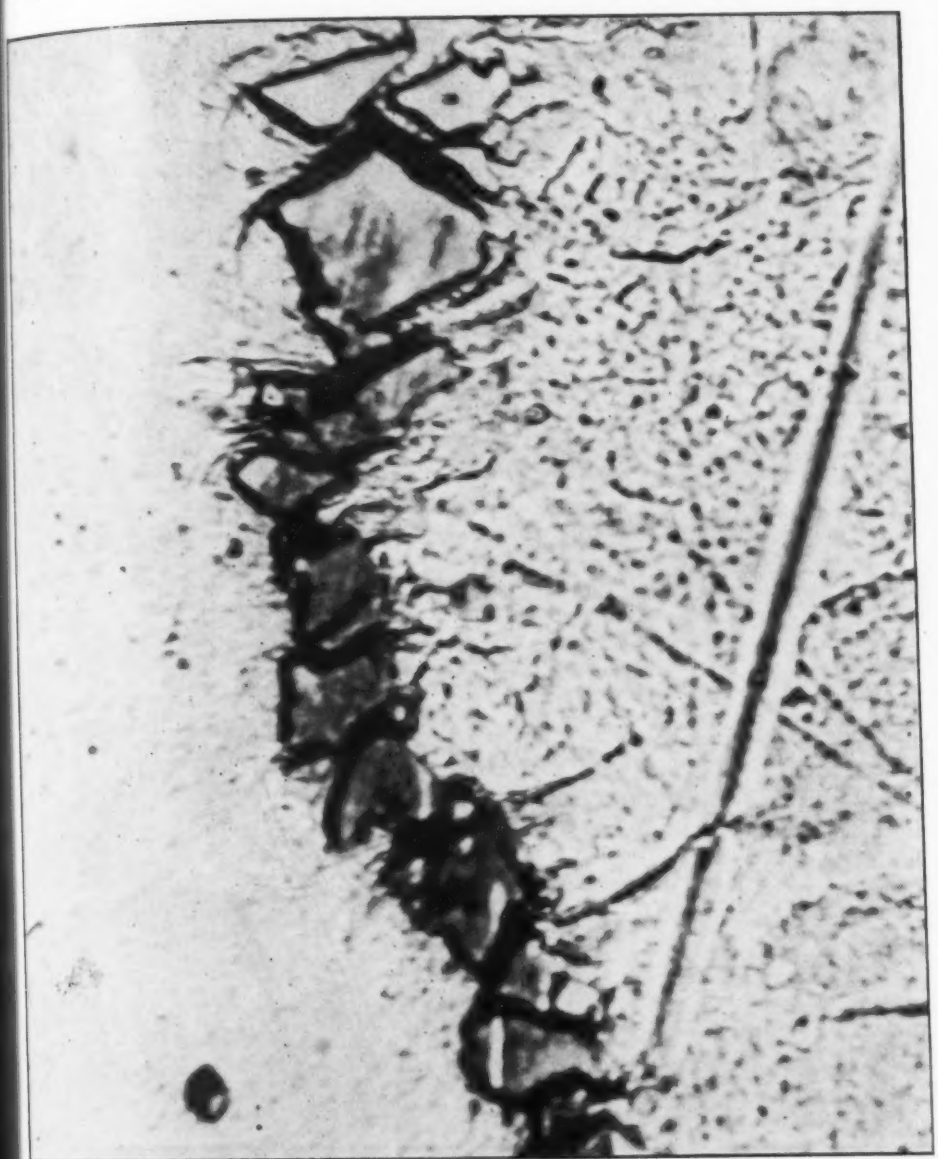


Fig. 1—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 2300 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 3-millimeter oil immersion, 1.32 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 60.5 centimeters.
EXPOSURE TIME: 1¾ minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is of an area of ingot iron showing cementite. It will be noted that these are polyhedral grains.

Fig. 2—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 2300 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: None.
1ST IRIS: 7.
2ND IRIS: Open.
RACK POSITION: 5 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 3-millimeter oil immersion, 1.32 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATOR: Conical.
CAMERA EXTENSION: 60.5 centimeters.
EXPOSURE TIME: 2½ minutes.
PLATES: Wratten M
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

Photomicrograph of the same section shown in Fig. 1, except that this photomicrograph was obtained by using conical illumination. The direction of the light was from left to right. By turning this picture upside down, the areas appearing raised in the first position, will be depressed in the second.

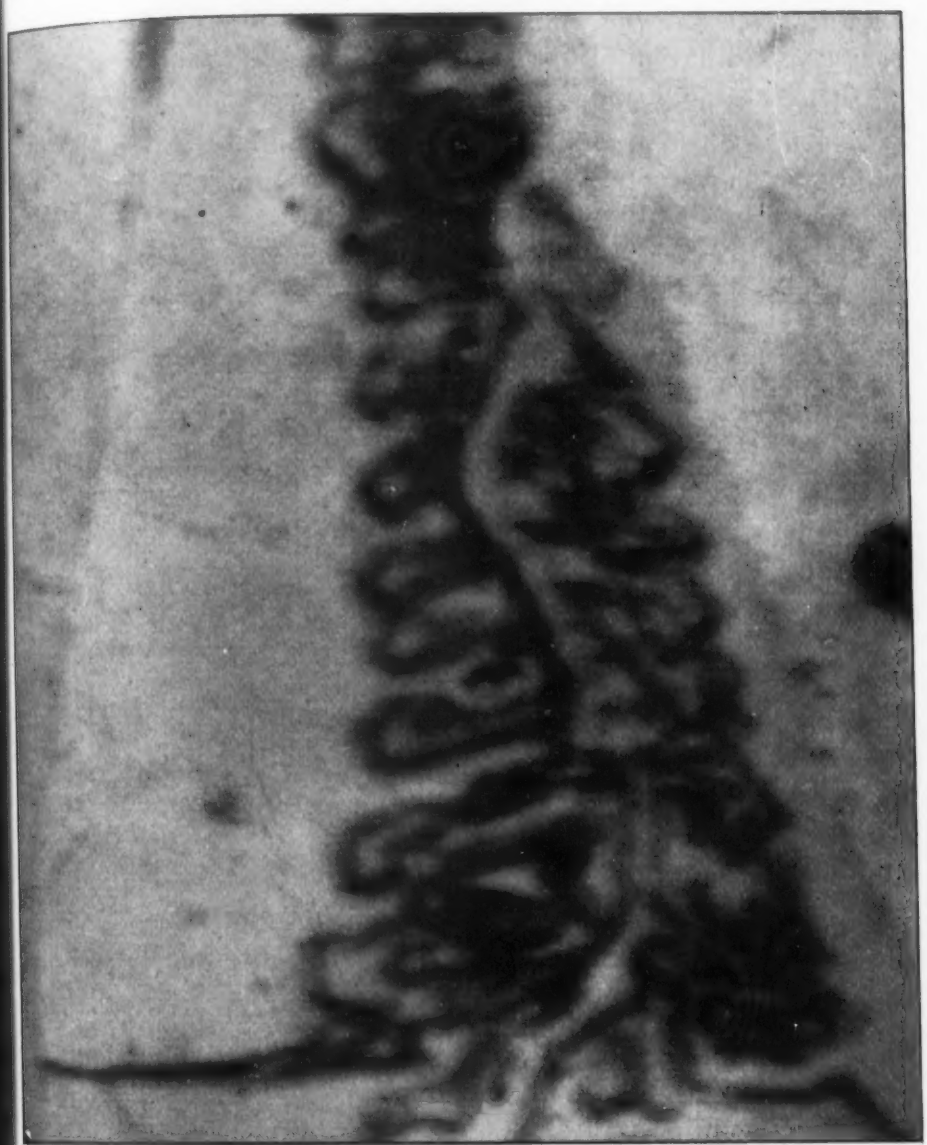


Fig. 3—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 3200 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 2½ minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph shows a streamer of cementite in the act of forming pearlite in a ferritic grain of an 0.02 per cent carbon ingot iron.

at this time but the results will show the desirability of using conical illumination at high magnifications.

Fig. 1 shows an area containing cementite in 0.02 per cent carbon ingot iron with flat plain axial illumination. The magnification is 2300 diameters, and a train or vertebræ of polyhedral grains is shown. Fig. 2 is of identically the same section and under the same conditions as the preceding plate, with the exception that conical illumination was used, giving a three dimensional effect.

The photomicrograph in Fig. 3 is that of cementite under axial illumination. This photomicrograph was made at 3200 diameters and shows a streamer of cementite in the act of forming pearlite in a ferritic grain in 0.02 per cent carbon ingot iron. Fig. 4 is identical with Fig. 3, with the exception that conical illumination has brought out details both as to the preparation of the sample and as to details of the structure involved. This is a striking illustration of the cementite sacrificing its identity and ferrite doing the same to form a condition we know as pearlitic. Small feelers are being fed from the large mass and these feelers will no doubt in time continue to send out further feelers from them to form lamellar pearlite. No doubt this massive cementite was in process of recession rather than of progression due to very slow cooling.

Fig. 5 is a pearlitic area in a hypo-eutectoid zone in the core of a carburized bar, at a magnification of 3500 diameters. Fig. 6 is the same area conically illuminated to bring out more of the detail and actual conditions.

The photomicrograph in Fig. 7 is that of a cementitic area in 0.02 per cent carbon ingot iron at 4400 diameters in which somewhat the same conditions are seen as are shown in the preceding photomicrographs. It is peculiar that throughout this sample there seemed to be an excess of cementite and very little actual lamellar pearlite. Fig. 8 is the same area conically illuminated.

Fig. 9 is a photomicrograph of pearlite taken at 5200 diameters. It will be noticed in this picture that the focusing has brought out the fact that the cementitic striations are white and stand out above the ferrite. In most photomicrographs of lamellar pearlite where the illumination is of the plain axial type, the

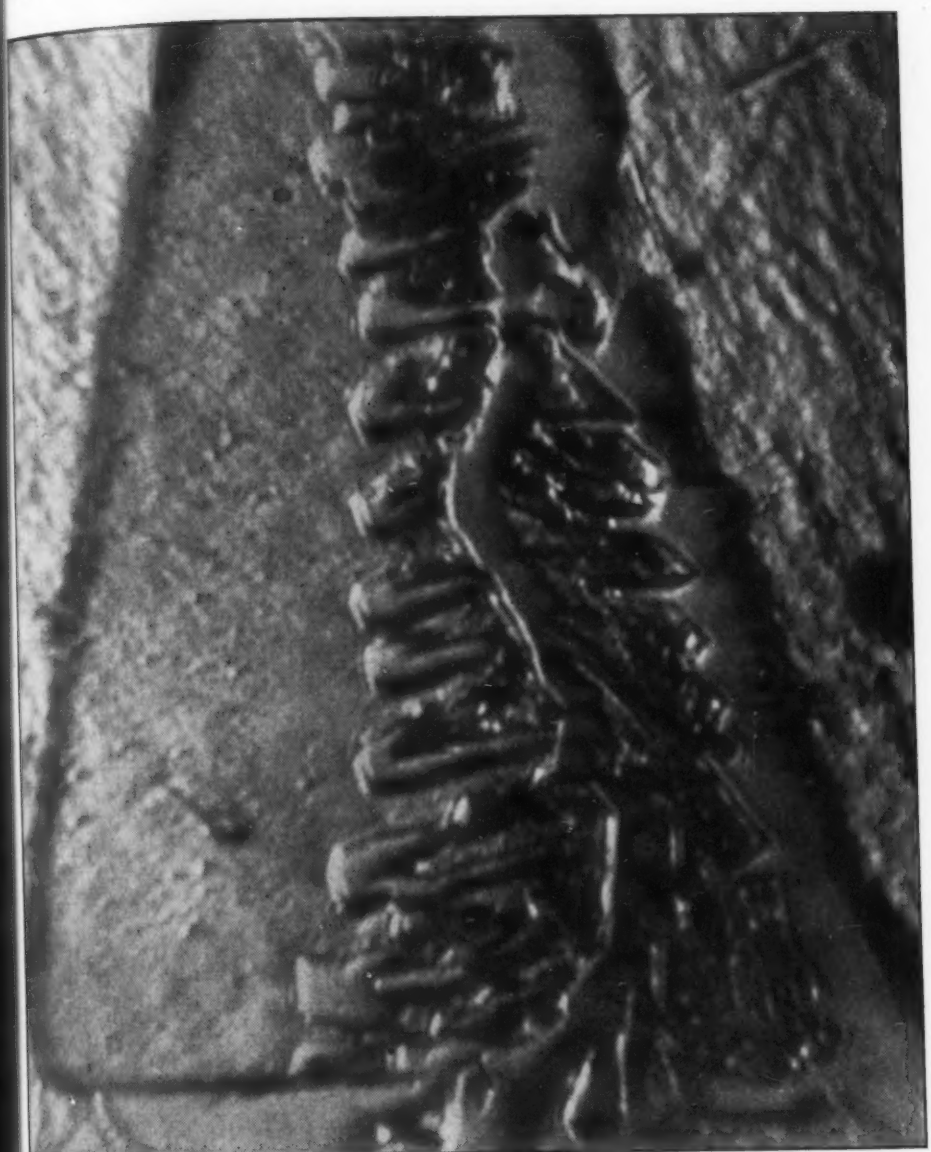


Fig. 4—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 3200 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: 5.
1ST IRIS: 7.
2ND IRIS: Closed.
RACK POSITION: 5 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Conical
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 5 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph shows the same area as that shown in Fig. 3 except that this photomicrograph was obtained by using conical illumination. The direction of the light was from the upper left-hand corner to the lower right-hand corner. By inverting the photomicrograph, the areas appearing raised in the first position become depressed in the second.

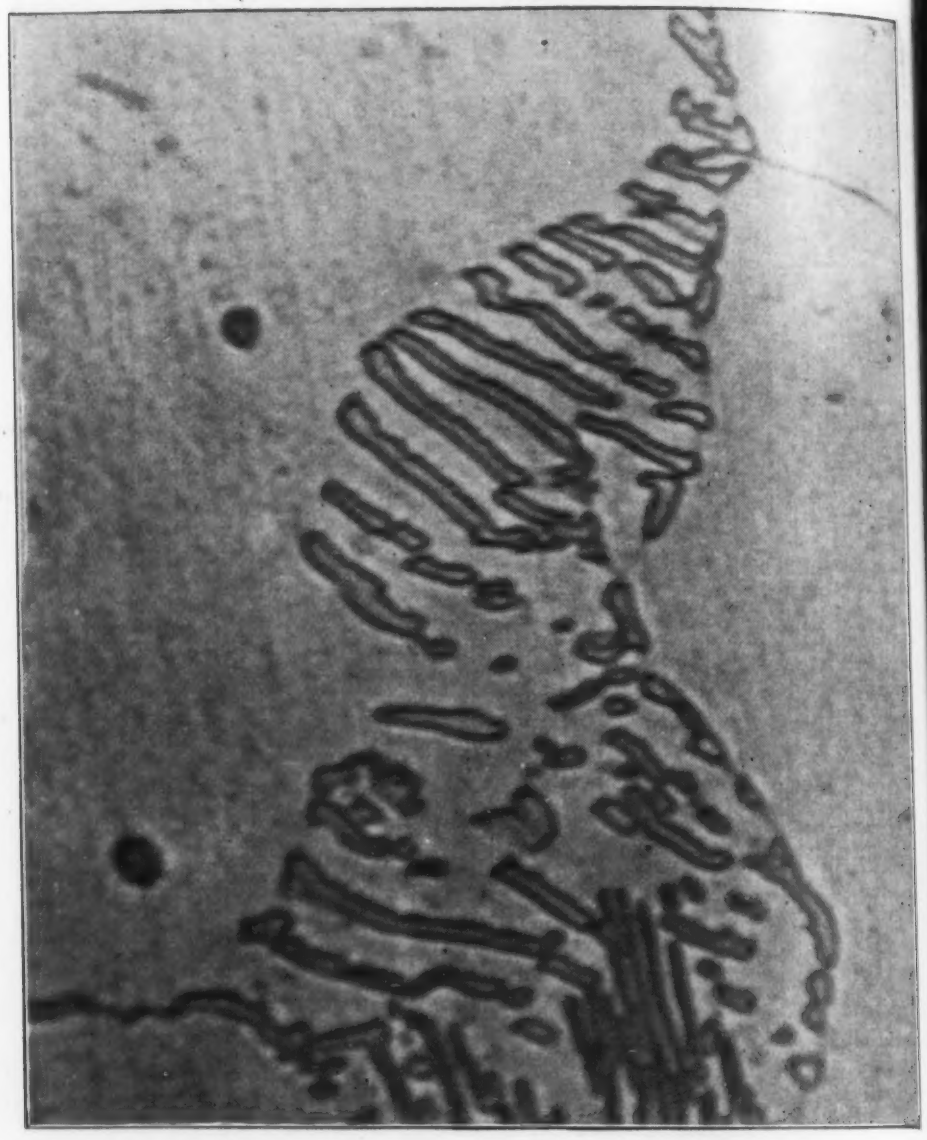


Fig. 5—Core of Carburized Steel. Magnification 3500 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 3-millimeter oil immersion, 1.32 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical
CAMERA EXTENSION: 91 centimeters.
EXPOSURE TIME: .2 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is that of a pearlitic area in the hypoeutectoid zone in the core of a carburized bar of steel.

Fig. 6—Core of Carburized Steel. Magnification 3500 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: 5.
1ST IRIS: 7½.
2ND IRIS: Closed.
RACK POSITION: 1 millimeter up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 3-millimeter oil immersion, 1.32 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 91 centimeters.
EXPOSURE TIME: 4 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph shows the same area as shown in Fig. 5, and is identical to Fig. 5, except that conical illumination was used in obtaining this photomicrograph. The direction of the light was from the top to the bottom.

Fig. 7—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 4400 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 87 centimeters.
EXPOSURE TIME: 3½ minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph was obtained from a cementitic area of an 0.02 per cent ingot iron.

Fig. 8—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 4400 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: No.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: 5.
1ST IRIS: 10.
2ND IRIS: Open.
RACK POSITION: 4 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 87 centimeters.
EXPOSURE TIME: 4½ minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is identical to Fig. 7 with the exception that conical illumination was used instead of vertical. The direction of the light was from the upper left-hand corner to the lower right-hand corner.

Fig. 9—Carburized Steel. Magnification 5200 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: None
1ST IRIS: 0.
2ND IRIS: Half Open.
RACK POSITION: 3 millimeters up.
ILLUMINATOR FOCUS: Center.

OBJECTIVE: 2-millimeter oil immersion, 1.32 NA apochromat
OCULAR: 12 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 43½centimeters.
EXPOSURE TIME: 9 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph was obtained from a pearlitic area in a carburized steel.

Fig. 10—Carburized Steel. Magnification 5200 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten B.
CONICAL STOP NO: 5.
1ST IRIS: 8.
2ND IRIS: Half Open.
RACK POSITION: 3 millimeters up.
ILLUMINATOR FOCUS: Center.

OBJECTIVE: 2-millimeter oil immersion, 1.32 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 43½ centimeters.
EXPOSURE TIME: 12 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is the same as Fig. 9 with the exception that conical illumination was used instead of vertical. The direction of the light was from left to right.

Fig. 11—Abnormal Steel. Magnification 7100 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.

OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 7 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph was taken of a pearlitic area in a carburized abnormal steel, vertical illumination being used. This steel was deeply carburized in order to bring out the abnormality of cementite. Samples showing abnormality seemed to exhibit many of these areas.

Fig. 12—Abnormal Steel. Magnification 7400 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten H.
1ST IRIS: 6.
2ND IRIS: Closed.
RACK POSITION: 3 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 22 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is the same as Fig. 11, conical illumination being substituted for the vertical. In making this photomicrograph, the plate was removed from the camera every 5 minutes and the image refocused. The direction of the light was from right to left.

Fig. 13—Abnormal Steel. Magnification 7400 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: None
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 7 minutes.
PLATES: Wratten M
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph was taken of a section in an abnormal pearlitic steel.

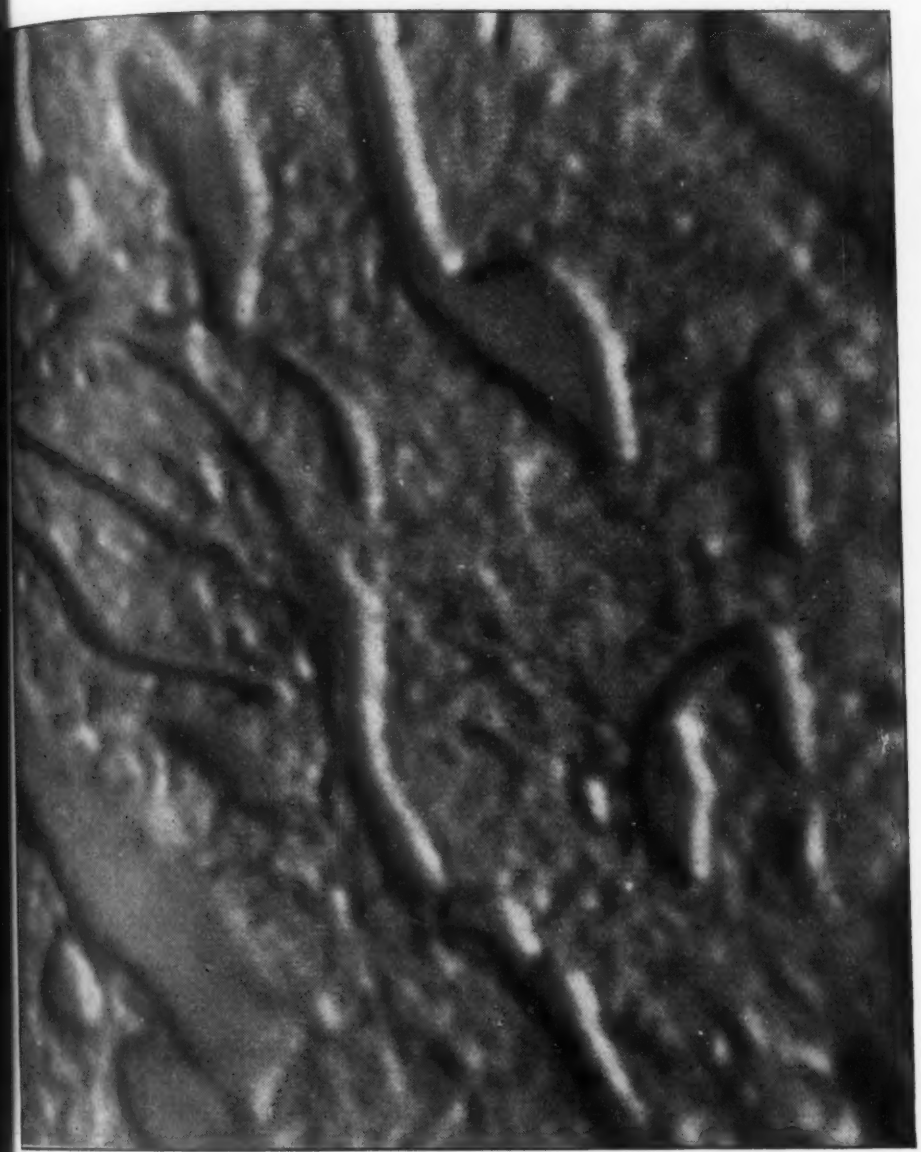


Fig 14—Abnormal Steel. Magnification 7400 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Wratten H.
CONICAL STOP NO: 5.
1ST IRIS: 6.
2ND IRIS: Closed.
RACK POSITION: 3 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Conical.
CAMERA EXTENSION: 61 centimeters.
EXPOSURE TIME: 15 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is the same as Fig. 13 except that conical illumination was used in place of vertical. The direction of the light was from right to left.

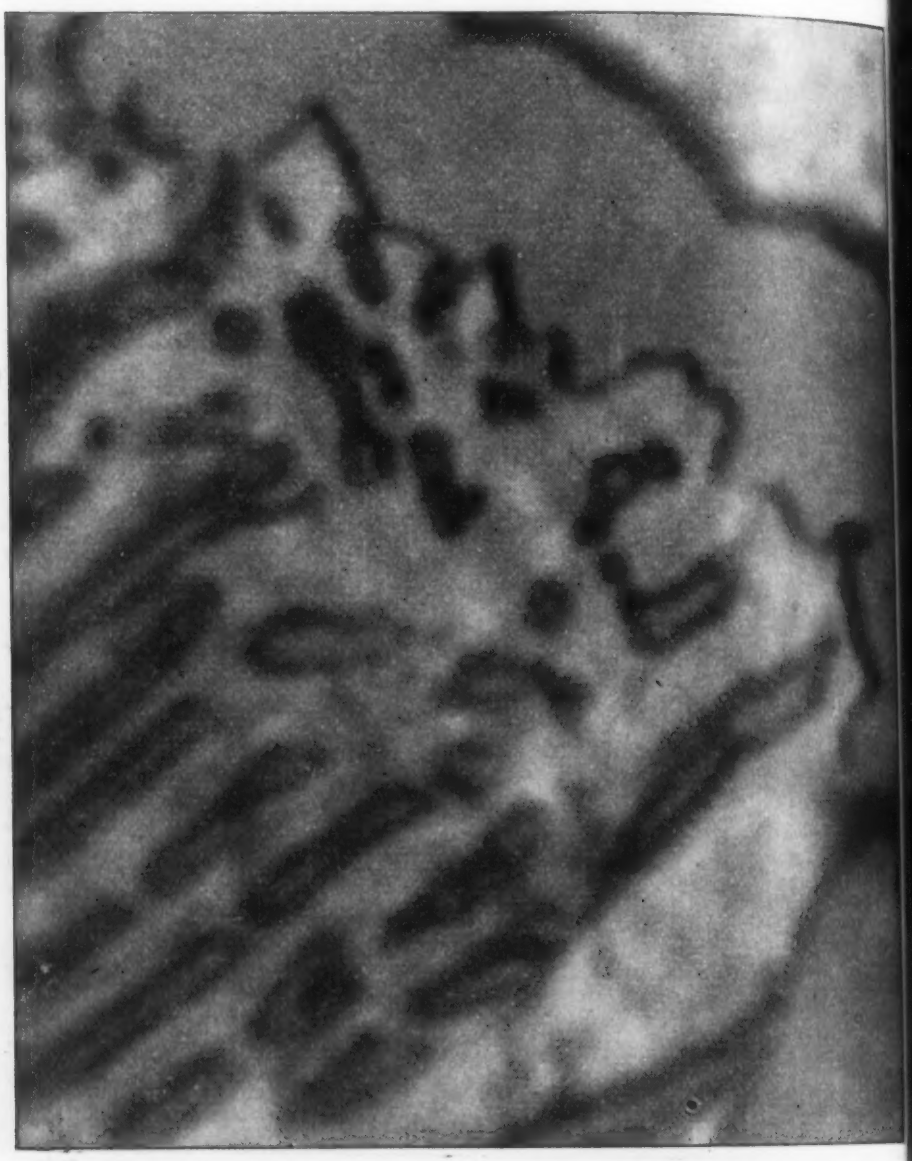


Fig. 15—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 8530 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: None.
1ST IRIS: None.
2ND IRIS: Closed.
RACK POSITION: None.
ILLUMINATOR FOCUS: Center.

OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 72 centimeters.
EXPOSURE TIME: 8 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph shows a pearlitic area in an 0.02 per cent carbon ingot iron having cementite borders, which seem to be common to this type of pearlitic area as shown in preceding photomicrographs.

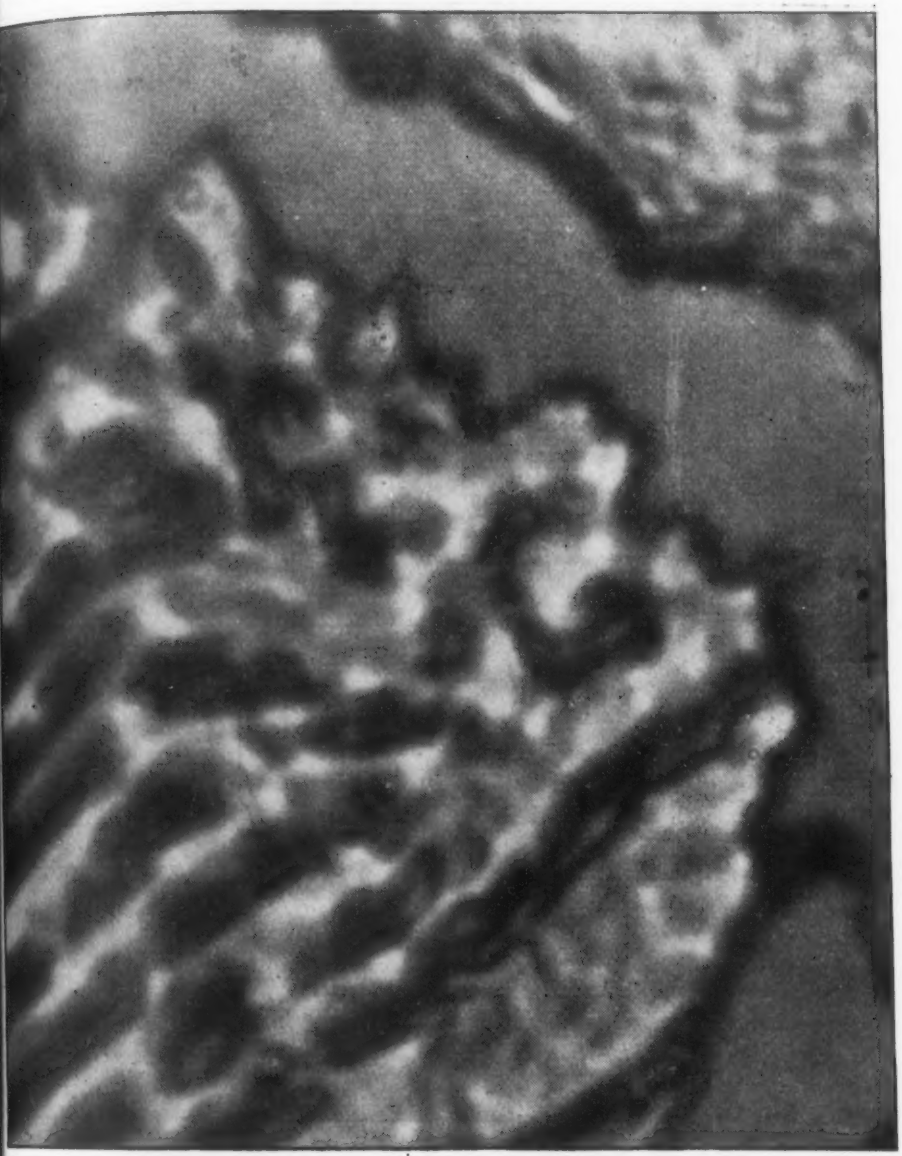


Fig. 16—Ingot Iron; Carbon Content 0.02 Per Cent. Magnification 8500 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Plain Green Glass.
CONICAL STOP NO: 5.
1ST IRIS: 20.
2ND IRIS: Closed.
RACK POSITION: 4 millimeters up.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 72 centimeters.
EXPOSURE TIME: 9 minutes.
PLATES: Wratten M.
SIZE: 5x7 inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph is the same as Fig. 15 with the exception that conical illumination was used.

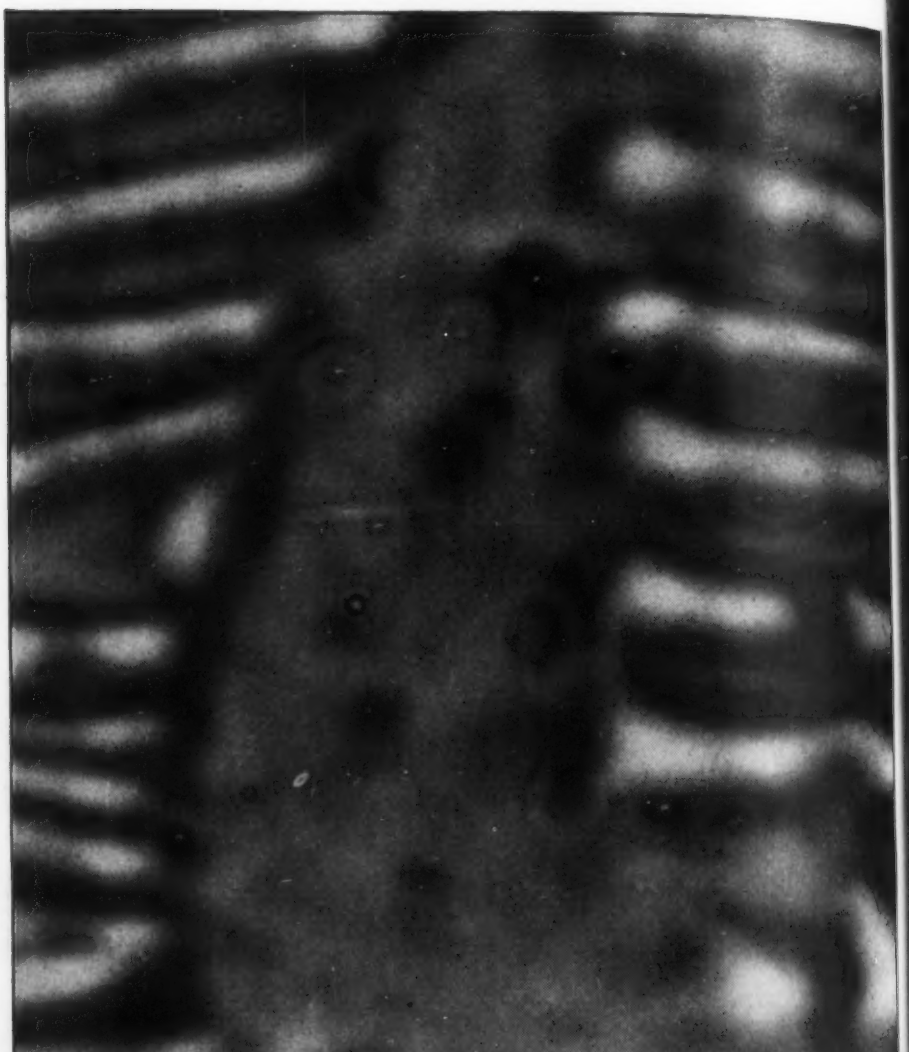


Fig. 17—Carburized Steel. Magnification 15,500 x.

ETCH: 1% Nitric Alcohol.
INSTRUMENT: Leitz Micro-Metallograph.
VIBRATION ABSORBERS: Yes.
ILLUMINATION: Arc.
FILTER: Small Blue-green Glass.
CONICAL STOP NO: None.
1ST IRIS: 15.
2ND IRIS: ½.
RACK POSITION: Center.
ILLUMINATOR FOCUS: Center.
OBJECTIVE: 2-millimeter oil immersion, 1.40 NA apochromat.
OCULAR: 25 x Periplan.
TYPE ILLUMINATION: Vertical.
CAMERA EXTENSION: 132 centimeters.
EXPOSURE TIME: 30 minutes.
PLATES: Wratten M.
SIZE: 6½x8½ inches.
DEVELOPER: Pyro-Soda.
TEMPERATURE: 70 degrees Fahr.
TIME: 2½ minutes.

This photomicrograph shows a pearlitic area of a carburized bar of steel, vertical illumination being used. The arc lamp was set at 20.8 centimeters from the microscopic stand. The condenser was normal and at the end of the diamond bar. So far as is known, this photomicrograph is the highest magnification that has ever been attained by a single projection.

focusing is done to bring the ferritic striations out and in consequence the cementite appears as black lines in a white matrix. Fig. 10 is the same field taken under conical illumination and shows much detail and also a granular or laminated appearance in one of the grains. These cross striations might show somewhat the individual grain formation or cubic formation shown in one of the later photomicrographs.

The photomicrograph in Fig. 11 was taken with plain axial illumination at 7400 diameters of a cubic, or vertebræ section, and this section, along with the pearlite, occurred in an abnormal pearlitic steel which was deeply carburized to bring out the abnormality in the formation of the excess cementite. Samples showing abnormality seem to exhibit quite a number of these areas. Fig. 12 is the same as Fig. 11, but conical illumination was used.

Fig. 13 was taken at 7400 diameters and shows cementite in a ferrite matrix from which all lamellar pearlite has been divorced. This area is also from the abnormal pearlitic steel previously mentioned and although this might appear to the casual observer to be abnormal in itself, it is doubtful if this is the case, being more likely massive cementite which was the result of slow cooling. But even this does not alter the fact that this field is abnormal but only serves to show that in many instances, particularly in slowly cooled specimens, a great many areas may be taken to be abnormal, which in reality may be massive cementite. There is, however, quite a fine distinction between a so-called abnormal cementite and that which assumes the massive proportions. Fig. 14 is identical with Fig. 13, with the exception that conical illumination was used.

Fig. 15, taken at 8500 diameters, shows a pearlitic area in ingot iron having a cementite border which is common to this type of pearlitic area as shown by the preceding photomicrographs —Figs. 3 to 8 inclusive. These cementitic areas are, no doubt, of the massive variety due to the extremely slow cooling of the ingot. Fig. 16 is identical with Fig. 15, excepting in this instance conical illumination was used.

The photomicrograph in Fig. 17 shows the absolute extreme magnification that the equipment used was capable of in every detail. So far as is known, it is the largest diameter ever attained by a single projection. This photomicrograph was taken at 15,500 diameters using conical illumination and shows conclusively the

cementitic striations ending at an area of free ferrite. It also further exemplifies that these two constituents are not at the same level.

Conclusion

To recapitulate, the essence of what has been said is simply this: Entirely too much mystery has surrounded this subject and it has been hailed as entirely too complicated. But the real facts are that equipped with an apparatus made for this type of work and samples prepared in some manner which gives about the results that the method of sample preparation herein described gives, and combined with absolute cleanliness throughout the entire operation from the rough grinding wheel to the finished print—the operator need have very little fear or apprehension as to the ultimate results.

The author wishes to make the point that high power photomicrography seemed complex to him about four years ago, but it is somewhat with embarrassment that he admits for the good of all that its complexity was due to his ignorance, and that after spending four years on this particular phase of metallography, he is able to write all he knows about it in fifteen minutes. This admission contains food for thought.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CHEMISTRY OF IRON AND STEEL*

By F. T. Sisco

Abstract

In the manufacture of iron in the blast furnace, iron ore, coke, and limestone are charged into the top of the furnace and preheated air blown in near the bottom. The oxygen in the blast reacts with incandescent coke to form carbon monoxide which, with carbon, reduces the iron oxide to metallic iron. As the iron melts it absorbs carbon up to 4.50 per cent. The manganese oxide and all of the phosphates in the furnace burden are reduced by carbon and dissolved by the iron. The silica and the sulphides in the charge are partly fluxed out with the slag and partly reduced and dissolved by the iron. The control of these two constituents depends upon slag composition, temperature, and fluidity. In the Bessemer process air under pressure is blown through molten iron. The silicon, manganese, and carbon are oxidized in the order named, the first two passing into the slag as silicates of iron and manganese, the latter burning away as carbon dioxide. Sulphur and phosphorus are not affected. Ferro-manganese or spiegeleisen is then added to recarburize, deoxidize and degasify the metal and thus produce sound steel.

The Chemistry of the Blast Furnace and the Manufacture of Iron

THE chemical reactions occurring in the smelting of iron ores in the blast furnace are even after many years of practical experience with the process, not wholly undestood. This is due to two factors: first, because so many variables of temperature, blast pressure, atmospheric conditions, and the like, influence the

*This is the second instalment of this series of articles. The first instalment appeared in the February, 1925, issue of Transactions, page 197.

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reactions; and second, as the blast furnace is a closed chamber into which solid materials are charged at the top and from which molten metal and slag are drawn at the bottom, the conditions in the furnace cannot be readily observed, but, rather, must be interpolated from observed phenomena at both the top and bottom or else worked out from theoretical considerations of what should happen in the furnace.

In the blast furnace, iron ore, coke and limestone are charged into the top, and air, preheated to about 1000 degrees Fahr. and under pressure, blown by several tuyeres, into the furnace near the bottom. The ore in its slow descent is reduced to iron by means of carbon monoxide and by carbon, the temperature gradually increasing from about 400 degrees Fahr. at the throat of the furnace to 3000 degrees Fahr. or more near the tuyeres, just above the hearth.

As the iron, in its descent, nears the zone of high temperature it starts absorbing carbon. As the quantity of carbon absorbed increases, the melting point becomes progressively lower, and with rising temperature the pasty iron finally becomes molten and trickles down over the incandescent coke into the hearth.

In the gangue or earthy matter accompanying the iron oxide in the ore, and in the ash of the coke are silica, aluminum oxide, manganese oxide, sulphides, phosphates and sometimes calcium and magnesium oxides. To flux out these impurities, limestone is charged with the ore and coke. The fusible slag resulting collects on top of the molten iron in the hearth, from which it is drained every few hours. This slag is a factor of great importance in the successful operation of the furnace and controls, to a large extent, the composition and quality of the iron.

In the smelting process the reduction of the iron oxide is accompanied by a partial reduction and absorption by the iron, of the silicon, sulphur and manganese and by a complete reduction and absorption of the phosphorus. The amount of the reduction of the first two elements is controlled partly by the slag, partly by the temperature and partly by the general method of furnace operation.

The chemistry of the blast furnace in its simplest form may be divided into four steps:

(1) The reduction of the iron oxide in the ore to iron:

(2) The reduction of the manganese oxide to manganese, and the phosphates to phosphides;

(3) The reduction of silica to silicon and the reaction of sulphur or FeS with calcium oxide to form CaS; and

(4) Proper control of furnace conditions which regulates the condition of the carbon in the iron.

The Reduction of the Iron Oxide in the Ore to Iron

In iron ore the iron occurs as ferric oxide, Fe_2O_3. It is reduced to iron by two general reactions:

$$(1)\quad Fe_2O_3 + 3\,CO \rightleftarrows 2\,Fe + 3\,CO_2$$
$$(2)\quad Fe_2O_3 + 3\,C \rightleftarrows 2\,Fe + 3\,CO$$

Both of these reactions are reversible and may proceed in either direction, depending on conditions and temperature present at that moment. Both reactions are assumed to be progressive:

$$(1a)\quad 3\,Fe_2O_3 + CO \rightleftarrows 2\,Fe_3O_4 + CO_2$$
$$(1b)\quad Fe_3O_4 + CO \rightleftarrows 3\,FeO + CO_2$$
$$(1c)\quad FeO + CO \rightleftarrows Fe + CO_2$$

and

$$(2a)\quad 3\,Fe_2O_3 + C \rightleftarrows 2\,Fe_3O_4 + CO$$
$$(2b)\quad Fe_3O_4 + C \rightleftarrows 3\,FeO + CO$$
$$(2c)\quad FeO + C \rightleftarrows Fe + CO$$

The above two groups constitute the principal reducing reactions in the furnace.

A reaction of great importance is that between the oxygen in the blast and the incandescent coke just above the tuyeres, in the hottest zone of the furnace. This reaction takes place in three ways:

$$(3a)\quad C + 2\,O \rightarrow CO_2$$
$$(3b)\quad CO_2 + C \rightarrow 2\,CO$$
$$(3c)\quad 2CO + 2\,O \rightarrow 2\,CO_2$$

Reaction (3b) is the predominating one, as there is always sufficient carbon present for its completion.

The carbon dioxide from reaction (3c) is augmented by the dissociation of the limestone, reaction (4):

$$(4)\quad CaCO_3 \rightarrow CaO + CO_2$$

which is practically complete at about 1800 degrees Fahr.

The carbon monoxide formed by reaction (3b) is augmented

by the reduction of carbon dioxide by metallic iron, reaction (5), at temperatures exceeding 1600 degrees Fahr.:

$$(5) \quad Fe + CO_2 \rightleftarrows FeO + CO$$

and by the dissociation of the water vapor in the blast, reaction (6), at temperatures exceeding 2000 degrees Fahr.:

$$(6) \quad H_2O + C \rightarrow 2\,H + CO$$

From reactions (3), (4), (5) and (6) it will be noted that both carbon monoxide, reducing in its action, and carbon dioxide, oxidizing in its action at elevated temperatures, may exist in the furnace gases at the same moment and that conditions in the furnace at any particular level and at any particular instant may be either reducing or oxidizing, depending whether carbon monoxide or carbon dioxide is in excess. This reducing or oxidizing condition is not only dependent on the predominance of one gas or the other but is also dependent on the temperature, blast pressure, downward pressure of the stock and other factors.

In general, carbon monoxide is the predominating gas and as it is reducing in its action at comparatively low temperatures, reaction (1) is going on steadily from an upper level where 600 degrees Fahr. is the average temperature down to a point in the furnace where about 2000 degrees Fahr. is reached.

The small amount of oxidation by carbon dioxide, reaction (7):

$$(7) \quad Fe + CO_2 \rightleftarrows FeO + CO$$

takes place first near the 1000-degree Fahr. level and is most active at still higher temperatures. (See reaction 5.)

At about 1000 degrees Fahr. reaction (2) starts, continuing down to a level where 2400 degrees Fahr. is the prevailing temperature.

It is important to note that the reduction by carbon monoxide, reaction (1), is exothermic and produces heat; while the reduction by carbon, reaction (2), is endothermic and absorbs heat; therefore the furnaceman attempts to operate the furnace so that carbon monoxide will accomplish the greater part of the reduction. In average practice the major part of the reduction of the iron oxide is accomplished (by reaction 1) in the upper levels of the

furnace; and by the time the charge has descended to the zone where sufficient heat is being supplied to make reaction (2) predominate—about 1800 degrees Fahr.—the ferric oxide, Fe_2O_3, has been mostly reduced to a mixture of ferrous oxide, FeO, and spongy metallic iron. Reaction (2) then completes the reduction.

It must be remembered, in connection with the chemical reactions involved in the smelting of iron ore, that the stock is settling downward very slowly, taking several hours to reach the hearth after being charged; but the gases are moving upward through the stock very rapidly only a few seconds elapsing between the entrance of the air at the tuyeres and the exit of the corresponding furnace gases through the downcomers.

So, continuously through the campaign of a furnace which may run day and night for years, we have ore, coke and limestone charged into the top, settling slowly to the hearth, meeting in its passage a steady stream of uprushing furnace gases, mostly reducing in their action, and an increasingly higher temperature as it descends, until, in the hottest zone of the furnace the metallic iron absorbs carbon, becomes mushy, absorbs more carbon and finally melts, only to absorb more carbon as it trickles down over the incandescent coke into the hearth.

The acid impurity in the ore, coke and limestone; silica, SiO_2, combines at high temperatures with the calcium oxide in the limestone to form a calcium silicate that melts below the melting point of the iron. This calcium silicate slag has the property of dissolving or holding in suspension other impurities and foreign matter in the iron ore and in the ash of the coke. This fusible slag, which floats on the molten iron in the hearth, may thus be readily removed and disposed of.

The coke escaping reaction with the iron oxide in the ore, sinks with the furnace burden until it meets the inrushing blast just above the tuyeres where it is totally consumed in the formation of carbon monoxide and carbon dioxide, reaction (3). The combustion of the coke with the hot blast supplies the intense heat necessary for the final reduction of the iron oxide, the melting of the iron and the formation and liquefaction of the slag.

The surplus heat generated by this combustion is transmitted to the uprushing furnace gas by which it is dissipated to the slowly settling stock.

Reduction of Manganese Oxide to Manganese and Phosphates to Phosphorus

The manganese oxide occurring in the ore is reduced, mostly by carbon as in reaction (8)

$$(8a)\quad MnO_2 + C \rightarrow Mn + CO_2$$
$$(8b)\quad MnO_2 + C \rightarrow MnO + CO$$
$$(8c)\quad MnO + C \rightarrow Mn + CO$$

and as such enters into the iron where it combines with carbon to form manganese carbide, Mn_3C, or with sulphur to form manganese sulphide, MnS. The amount reduced depends on furnace conditions; as a rule, practically all of the manganese oxide in the ore, if present in normal amounts, is reduced. Only a trace is ordinarily found in slags from furnaces operated normally. A highly basic slag, that is, a slag containing an excess of lime, will promote complete reduction of all of the manganese oxide in the burden; but a slag containing free silica tends to hold manganese in the slag as manganese silicate. As the slag of all regularly working furnaces contain about 40 per cent lime and usually less than 30 per cent silica, the excess of lime being essential to sulphur elimination, the complete reduction of manganese oxide to the element and its absorption by the iron is assured.

In ferromanganese and spiegeleisen smelted from manganese ores the reduction may not be complete, due to the large excess of manganese. In this case the furnace slag which contains considerable manganese oxide is often charged back into the furnace and smelted again.

Phosphorus entering the furnace with the ore, and traces in the coke and limestone is entirely reduced from some phosphate of the acid anhydride, P_2O_5, according to reaction (9):

$$(9)\quad P_2O_5 + 5\,C + 6\,Fe \rightarrow 2\,Fe_3P + 5\,CO$$

This reaction is always complete; all of the phosphorus in the furnace burden going into the iron as iron phosphide, Fe_3P.

With an excess of carbon, as is always the case in the blast furnace, reaction (9) is not reversible; it always proceeds in the direction indicated. Unless oxidizing conditions are present, and then only with a basic slag, phosphorus cannot be eliminated from iron or steel. In the blast furnace the basic slag is present, but furnace conditions are reducing, not oxidizing.

The Reduction of Silica to Silicon and Sulphides to Sulphur and the Control of These Two Elements

Silica is present in appreciable amounts, often up to 10 per cent or more, in the ore; likewise it is present in the ash in the coke and in the limestone. Nearly all of this constituent combines with the calcium oxide to form the slag. A varying small amount is reduced by carbon at the very high temperature of the bosh, by reaction (10),

$$(10) \quad SiO_2 + 2\,C + Fe \rightarrow FeSi + 2\,CO$$

and goes into the iron as iron silicide, FeSi (Fe_2Si).

As the heat of oxidation of silicon is very high, a large amount of heat is necessary for the reduction of its oxide. Below 2640 degrees Fahr. silica cannot be reduced by carbon alone. Above this critical temperature the reduction occurs only when heat is supplied fast enough; and is easier and more rapid, the higher the temperature. The upper part of the hearth near the tuyeres is the only zone where the reaction can take place. Another factor entering into this reduction is slag composition. A highly basic slag, that is, a proportion of lime, CaO, much in excess of that necessary for all of the silica present, tends to prevent the reduction of silica to silicon. Consequently in order to insure a high percentage (2 per cent or more) of silicon in the iron and still keep the slag sufficiently basic for sulphur removal, a high temperature, considerably above 2640 degrees Fahr., must be maintained with correspondingly high coke consumption.

From the above we have seen that the conditions favorable for silicon reduction and a resulting percentage of 1.50 to 4 or more in the iron are:

(1) Furnace temperature very hot, slag normal;

(2) Furnace temperature normal, slag deficient in bases; and the conditions unfavorable for silicon reduction, producing a low silicon (between 0.50 and 1.50 per cent) iron are:

(1) Furnace temperature normal, slag very basic;

(2) Furnace temperature cold, slag normal.

The conditions necessary for silicon control as enumerated above are further complicated by those necessary for sulphur removal.

Sulphur which is present in the furnace burden principally as sulphides, goes directly into the iron as iron or manganese sulphide, unless it is fluxed out by the calcium oxide, reaction (11)

$$(11) \quad FeS + CaO + C \rightarrow CaS + Fe + CO$$

and as calcium sulphide, CaS, is dissolved and held by the slag.

There are several factors that influence desulphurization; the two most important are temperature and relative basicity and condition of the slag. Carbon is essential to the reduction of iron sulphide and the formation of calcium sulphide by reaction (11). This may be left out of the discussion, as there is always sufficient carbon present in the blast furnace.

The first and most important condition for sulphur removal is a basic slag. The formation of calcium sulphide depends on the presence of calcium oxide in excess of that necessary to combine with all of the acid (silica). Calcium sulphide is soluble in a basic slag; but the solubility depends upon the excess of calcium oxide, the fluidity and the temperature. A thin slag tends to hold calcium sulphide better than a thick, viscous one. Also a high temperature is favorable for sulphur removal. These last two considerations are dependent on each other, for, assuming the composition of the slag to be constant, a high temperature promotes fluidity; with a low temperature the opposite is true.

Summing up we find that desulphurization takes place in the blast furnace when the following conditions are met:

(1) Furnace temperature very hot, slag normal;

(2) Furnace temperature normal, slag very basic;

and high sulphur (above 0.060 per cent) may be present in the iron from:

(1) Furnace temperature normal, slag deficient in bases;

(2) Furnace temperature cold, slag normal.

Combining the possibilities for silicon and sulphur control we find that four conditions are possible:

(1) Furnace temperature very hot, slag normal; high silicon and low sulphur;

(2) Furnace temperature normal, slag very basic, low silicon and low sulphur;

(3) Furnace temperature normal, slag deficient in bases, high silicon and high sulphur; and

(4) Furnace temperature cold, slag normal, low silicon and high sulphur.

It must be remembered that the above four sets of conditions are subject to many variables, and, consequently, may hold true only in a general way. For example, a hot furnace is a relative term only; a very high temperature for one grade of ore and coke may be a normal temperature for another; likewise normal slag is a relative term in that a normal slag at one temperature and for one class of ore may be a very basic slag or a slag deficient in bases for some other temperature or other grade of ore.

In the same way, some of the conditions noted above contain apparently contradictory factors. An example of this is No. 2. A very basic slag can usually only be obtained at a sacrifice of some fluidity, hence with a normal temperature a very basic slag may be thick and viscous and not so efficient in sulphur elimination. To obtain the desired fluidity and still maintain an excess of bases a higher furnace temperature must be used to keep the slag sufficiently fluid. These points are noted to give a general idea of the problems faced by the furnace operator in controlling the percentages of silicon and sulphur. As a rule the furnaceman operates his furnace as closely to ideal conditions as possible; after taking into consideration the quality of his ore, coke and limestone and the cost of each, he regulates the burden and temperature in such a way that he obtains his results with a minimum cost and yet produces a maximum output of a satisfactory quality.

Factors Influencing the Condition of the Carbon

Carbon may exist in iron in two forms; as the element, graphite; or as a compound with iron,—cementite, iron carbide, Fe_3C. A small amount is combined with the manganese as manganese carbide, Mn_3C. As this constituent is similar to iron carbide chemically a discussion of cementite would also hold for the small amount of manganese carbide present.

In the iron-carbon equilibrium system, graphite is a stable phase, while cementite is meta-stable. Leaving aside other factors, the cementite, therefore, tends to break down into elementary carbon and iron, reaction (12):

$$(12) \quad Fe_3C \rightarrow 3\,Fe + C$$

There are several factors that influence this change to stable

equilibrium; some work toward a prevention of reaction (12) others work toward accelerating the change.

The two main considerations in the condition of the carbon in cast or pig iron are (1) rate of cooling from the liquid state to below 1000 degrees Fahr. and (2) the influence of the other elements in the iron on the carbon.

Other things being equal, a slowly cooled iron will contain a larger percentage of the carbon as graphite than a rapidly cooled iron. For example: A one-inch cast iron bar contains 1.00 per cent combined carbon (iron carbide, Fe_3C) and 3.00 per cent graphite. If the same iron was cast into a block weighing two to three tons the combined carbon would be practically nil, while the graphite would be nearly 4.00 per cent. This, of course, assumes that the change has not been influenced by the chemical composition. Aside from the influence of the other elements in iron, the rate of cooling plays the most important part in the final condition of the carbon. Some years ago when most blast furnace iron was sand cast, pig iron could be graded correctly by the appearance of the fracture. In fact, this was the sole method of many furnace plants and foundries. The more rapid chilling of the iron when mechanically cast in pig casting machines has a great influence on the condition of the carbon and thus on the character and appearance of the fracture. Consequently such iron is now bought and sold solely on chemical analysis.

The elements that have the most influence on the condition of the carbon are silicon and sulphur. Manganese is thought by some to favor the retention of iron carbide, and thus prevent the precipitation of graphite. There is, however, some doubt about this. Phosphorus, as far as we know, has practically no influence on the final condition of the carbon. The element does, however, influence the appearance of the fracture. Due to the phosphide eutectic the fracture appears lighter in color than a corresponding iron with less phophorus.

Silicon is active in promoting the precipitation of graphite. It is thought that some silicon exists as iron-silico-carbide, which breaks up easily on cooling to iron silicide, throwing the carbon out of solution as graphite. Silicon decreases the solubility of carbon in iron. The eutectic of iron-iron carbide in the iron-carbon system appears at 4.30 per cent carbon. With 1.00 per cent silicon

present the carbon percentage of the eutectic is reduced to 3.93 per cent and with 2.00 per cent silicon to 3.80 per cent carbon.

Other things being equal, the influence of the silicon on the final condition of the carbon is so important that foundry iron for different classes of castings is sold according to silicon content.

When sulphur is present in iron in its normal state (as manganese sulphide) the element probably has very little effect on the condition of the carbon. As iron sulphide, FeS, in which state considerable may exist in high sulphur irons, it acts as a stabilizer for the iron carbide and tends to prevent its dissociation, thus producing relatively hard, white iron. In general, the effect of sulphur is likely to be offset by the much larger amount of silicon usually present.

Summing up then, we may say that in general, assuming that the amount of sulphur is normal, 0.060 per cent or below and that at least 0.50 per cent manganese is present, the percentage of silicon and the rate of cooling are the two most important variables in regulating the amount of graphite and combined carbon present in ordinary pig and cast iron.

Slow cooling will produce a relatively large amount of graphite. The amount of this elementary carbon will be still greater if the percentage of silicon is high (1.50 per cent or above). Rapid cooling favors the retention of the meta-stable cementite. This retention may be intensified by a low silicon percentage or partially prevented by a high silicon percentage.

The Chemistry of the Bessemer Process

In the acid Bessemer process ten to twenty-five tons of molten pig iron are charged into an acid-lined converter. Air under pressure is blown through a number of tuyeres in the bottom, and passing rapidly through the metal, oxidizes the silicon, manganese and carbon in the order named. This oxidation is accompanied by (1) flames of varying intensity and color; (2) by a violent ebullition of the metal; (3) by the formation of a slag having acid characteristics and (4) by a rapidly increasing temperature. It is also accompanied by a severe oxidation and probable saturation of the molten iron with oxides and gases. The process of conversion, or blowing, takes from 8 to 12 minutes, after which the metal is ready for pouring. Deoxidation and recarburi-

zation are accomplished by molten spiegeleisen or solid ferromanganese or in some cases by an alloy of silicon and manganese or by both ferromanganese and ferrosilicon. After two or three minutes, during which the steel is freed, as far as possible from oxides, reaction products and gas, the ingots are teemed.

The chemistry of the acid Bessemer may be diverted into three steps:

(1) The oxidation of the silicon and manganese;
(2) The oxidation of the carbon;
(3) Deoxidation and recarburization of the blown metal.

As the converter has an acid lining, and as the slag formed is strongly acid (due to 50 per cent or more silica, SiO_2) the two impurities in the iron, sulphur and phophorus, are not even partially removed. In fact because of the loss in weight of the charge due to the oxidation of silicon, manganese, carbon and some iron, the amount of phosphorus and sulphur increases about 10 per cent.

The acid process is the only form of Bessemer conversion used in this country. In Europe the basic Bessemer process is common. In this practice the converter is lined with basic refractories and lime used for a slag. The phosphorus is oxidized by an after-blow and passes into the slag where it is held as calcium phosphate. A high percentage (1 to 2 per cent) in the pig iron is necessary for the successful completion of the after-blow. In the United States no ores are sufficiently high in phosphorus to make the basic Bessemer economically practicable.

The Oxidation of the Silicon and Manganese

The oxygen which is introduced through the 200 or more tuyere holes at the rate of about 800 cubic feet of air per minute, in striking the molten metal immediately oxidizes all of the elements with which it comes into contact. As iron predominates immediately above the tuyeres, iron oxide, FeO, is formed in large quantities:

$$(1) \quad 2\,Fe + O_2 \rightarrow 2\,FeO$$

This reaction liberates considerable heat. As the iron oxide, which is soluble in the metal, becomes distributed, the manganese and silicon oxidize according to their respective heats of formation;

silicon having the highest goes first; manganese follows quickly:

(2) $2\,FeO + Si \rightarrow 2\,Fe + SiO_2$

(3) $FeO + Mn \rightarrow Fe + MnO$

The silica, SiO_2, and manganese oxide, MnO, formed, separate immediately from the metal to form slag, reaction (4) and (5):

(4) $2\,FeO + 3\,SiO_2 \rightarrow (FeO)_2(SiO_2)_3$

(5) $2\,MnO + 3\,SiO_2 \rightarrow (MnO)_2(SiO_2)_3$

It is certain that there is some carbon monoxide formed even at the low temperature prevalent at the beginning of the blow, either by reaction (6) or (7):

(6) $FeO + C \rightarrow Fe + CO$

(7) $2C + O_2 \rightarrow 2\,CO$

Part of the carbon monoxide formed reacts with more of the iron oxide, FeO, to form carbon dioxide, reaction (8):

(8) $FeO + CO \rightarrow Fe + CO_2$

As long as there is residual silicon or manganese present, the carbon is not able to hold its oxygen at the prevailing temperature; most of the carbon monoxide or dioxide that is present is reduced by reaction (9), (10) or (11):

(9) $CO_2 + Si \rightarrow SiO_2 + C$

(10) $2\,CO + Si \rightarrow SiO_2 + C$

(11) $CO + Mn \rightarrow MnO + C$

although some carbon monoxide and a little carbon dioxide are found in the waste gases even in the first two or three minutes of the blow.

Of the above reactions, the second and third especially are productive of a large amount of heat which serves to increase the temperature of the metal from about 2450 degrees Fahr. to almost 3000 degrees Fahr.

Summing up the first step in the chemistry of the Bessemer process it is seen that:

(1) The oxygen in the blast is converted to iron oxide, FeO;

(2) The manganese and silicon in the iron reduce the iron oxide formed to metallic iron and thus they become oxides, combining with some iron oxide that escapes reduction to form a slag of manganese and iron silicates;

(3) Carbon reduces part of the iron oxide and forms carbon monoxide and carbon dioxide gas, but before this can escape in considerable amounts it is in turn partly reduced by manganese and silicon, which on account of their greater affinity for oxygen must both be supplied before the carbon can be oxidized permanently. The temperature of the blow is not high enough during this initial period to promote complete carbon oxidation, which only takes place rapidly and completely above a certain critical temperature;

(4) The oxidation of the silicon and manganese generates a large amount of heat, sufficient to raise the temperature of the bath several hundred degrees.

The Oxidation of the Carbon

In three to six minutes after the blast is turned on all of the silicon and manganese are eliminated. The temperature is now high enough to promote the rapid oxidation of the carbon. As there are no elements present that have a greater affinity for oxygen than carbon, reaction (12) and (13) go to completion:

$$(12) \quad FeO + C \rightarrow Fe + CO$$

$$(13) \quad FeO + Fe_3C \rightarrow 4\,Fe + CO$$

The carbon monoxide escaping in great quantities burns to carbon dioxide in the air, forming the brilliant and striking carbon flame of the Bessemer process. The dropping of the flame indicates that the carbon is almost completely oxidized. When the flame has nearly died away the carbon percentage is 0.08 or below.

All during the blow, due to the rapid passage of the blast through the metal, the bath boils violently, often ejecting liquid particles of slag and metal out of the mouth of the vessel. This loss through ejection is sometimes as much as 2 per cent of the weight of the steel and gives to the operation the showers of sparks that is such a common sight in converter practice. At times during the blow, a dense brown fume or smoke is given off, caused probably by colloidal iron and manganese oxides.

Bessemer Slags

Bessemer converter slags consist of manganese and iron sili-

cates represented by the formula:

$$[(FeO)_2(SiO_2)_3]x[(MnO)_2(SiO_2)_3]y[(SiO_2)(Al_2O_3)]z$$

or more simply:

$$(Fe_2Si_3O_8)x(Mn_2Si_3O_8)y(SiO_2.Al_2O_3)z$$

The slag is made up of iron, manganese and silicon oxidized from the iron with varying amounts of silica and a little aluminum oxide taken up from the lining. Small amounts of calcium and magnesium oxides find their way into the slag from traces of the blast furnace slag on the iron when poured into the vessel.

In the Bessemer slag, iron and manganese oxides act as bases, silica forming the acid constituent. The slag ratio is generally one to three; the oxygen of the base (FeO + MnO) is one part and the oxygen of the acid (SiO_2) is three parts. These slags are composed of tri-silicates and are moderately fusible especially if they are partly made up of bi-silicates (oxygen ratio of one to two). With a larger percentage of bases, about 20 per cent manganese oxide for example, the slag is thin and watery. In this condition operating troubles are encountered. To control the slag ratio it is essential that both the silicon and manganese in the pig iron be kept within a certain range. Control of these two elements in the pig iron is also essential because they are both heat producing elements. Due to the heat liberated when these two elements are oxidized it is sometimes difficult to keep the temperature of the bath down to reasonable limits. In regular practice the addition of cold scrap steel serves this purpose.

Reactions in Deoxidation and Recarburization

As we have already noted, ferromanganese or spiegeleisen are always added to blown Bessemer metal before pouring. The object in using the iron-manganese alloys is threefold: (1) to recarburize; (2) to deoxidize and degasify; and (3) to put the sulphur in the comparatively harmless form of manganese sulphide and thus eliminate hot shortness.

The removal of the dissolved ferrous oxide is accomplished principally by the manganese in the alloy, reaction (14):

$$(14)\quad FeO + Mn \rightarrow MnO + Fe$$

although the carbon and silicon in the ferro-alloy aid in deoxidation by reactions (15) and (16):

$$(15) \quad FeO + C \rightarrow CO + Fe$$

$$(16) \quad 2\,FeO + Si \rightarrow SiO2 + 2\,Fe$$

Reaction (15) with the carbon is very noticeable in the large volumes of carbon monoxide gas that escape just after the alloy is added. This is more evident if spiegeleisen is used than with ferromanganese, as more carbon is introduced into the steel with the former alloy. While most of this gas escapes, that which remains entrapped forms minute holes in the solid ingot. These holes are known as blow holes and sometimes cause serious defects in the rolled bar or billet. This will be discussed later.

Another reaction with the manganese alloy is (17):

$$(17) \quad FeS + Mn \rightarrow MnS + Fe$$

This reaction, as we have already seen, serves to put the sulphur into a relatively harmless form and prevents hot shortness.

In making low carbon steels by the Bessemer process the recarburizer is usually solid ferromanganese. As this alloy contains 80 per cent manganese and about 7 per cent carbon, considerable manganese may be introduced into the metal without the addition of much carbon. When medium and high carbon steels are made, spiegeleisen which contains 20 per cent maganese and about 5 per cent carbon is used. The carbon-manganese ratio with this alloy is 1 to 4, while with ferromanganese it is about 1 to 12. As a relatively large amount of spiegeleisen must be used in making medium and high carbon steels, the alloy is melted in a cupola and added molten to the blown metal. In case very sound steels are desired ferrosilicon or silicomanganese may be used as an additional deoxidizer.

(*To Be Continued in April* TRANSACTIONS)

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT

By H. B. Knowlton

Abstract

This paper discusses in a fundamental way the facts concerning wrought iron, cast iron, steel, and their heat treatment. It likewise discusses methods of testing the quality or physical properties of these materials.

The tensile test, impact tests and hardness tests are discussed in detail.

The hardening of steels and a discussion of the changes taking place in steel during heating and quenching is included.

Introduction

A PAPER which presents the simple facts about steel and its heat treatment should naturally begin with a short description of what steel is and what the differences are between the steels and the other members of the iron family. The different steels, cast irons, and wrought irons, consist chiefly of the metal iron. The differences between these materials lie in the quantities of substances or elements other than iron, which they contain. The steels usually contain from 75 to over 99 per cent iron. The ordinary *plain carbon* steels contain 98 to 99 per cent iron. The small amounts of other elements which make up the other 1 to 2 per cent contribute to the differences in the strength, toughness and hardening power of these steels.

Cast Iron

The cast irons contain more carbon than do the steels. They usually contain over 1.70 per cent carbon, from 1 to 3 per cent silicon and varying amounts of manganese, sulphur and phosphorus. Without discussing the exact nature of each of these elements or the effect each has upon the cast irons, let it be said that the weakness and brittleness of the cast irons, as compared to the steels, is due largely to these elements; principally carbon.

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Wrought Iron

The best grades of wrought iron are nearly chemically pure iron, plus small fibers of slag. They are different from the other members of the iron family in that they are not melted and poured, but are removed in a pasty condition from the furnace in which they are made. On account of their low content of carbon, manganese, sulphur and silicon, the wrought irons are very tough. They are not as strong as the steels, and generally cannot be hardened appreciably, due to low carbon and manganese content. Wrought iron may be defined as a slag-bearing, malleable material, which does not harden appreciably when suddenly cooled from a high temperature.

As an example of the commercial grades of wrought iron which are obtainable, the U. S. Navy has the following specifications covering the properties* of wrought irons used in navy work:

	Tensile Strength Pounds per sq. in.	Elong. in 2 in.	Red. of Area in per cent	Phosphorus per cent	Sulphur per cent
First Grade	48,000	26	40	Less than 0.12	Less than 0.015
Second Grade	45,000	25	40	Less than 0.15	Less than 0.02

The general specification for wrought iron would be a material made in a puddling furnace having a carbon content of less than 0.12 per cent and containing between 1 and 2 per cent slag. It would have a tensile strength of 40,000 to 50,000 pounds per square inch, an elongation of 25 per cent in 2 inches, and a reduction of area of 40 per cent.

Steel

Steel may be defined as an iron-carbon alloy which contains from 0.035 to 1.70 per cent carbon. Such a material is removed in a molten condition from the furnace in which it is made. Any definition of steel should include manganese because all present day steels include at least 0.10 per cent manganese. This definition distinguishes between the very low carbon steels and ingot iron which contains considerably less than 0.10 per cent manganese. An alloy may be defined as a substance usually composed of two or more metals intimately united, usually by fusing the components together. In the case of the carbon steels, we have

*For an explanation of these properties see page 382.

an alloy formed by the union of a metal (iron) and a non-metal (carbon). In the case of the alloy steels we have an alloy formed by the union of carbon, iron and the alloying elements such as nickel, chromium, vanadium, etc. This union usually takes place at an elevated temperature (melting) or it may take place at a lower temperature (carburizing). There are many grades of steel on the market but they are roughly divided into two general classes, the *plain carbon* steels and the *alloy* steels.

Plain Carbon Steels

While all steels are truly alloys, the steels in which the iron and the carbon are the principal alloys, are usually called plain carbon steels and the ones in which other metallic elements in addition to carbon are intentionally added to produce certain physical properties, are called alloy steels. Even the plain carbon steels contain small amounts of other elements besides iron and carbon. Some of these are elements which the manufacturer of the steel failed to remove and some of them are elements which are added intentionally to make the steel cleaner and more sound. In the main, the composition of the plain carbon steels falls between the following limits:

	Per Cent	Per Cent
Carbon	0.03	1.70
Manganese	0.10	0.80
Sulphur	0.005	0.12
Phosphorus	0.005	0.10
Silicon	0.10	0.35
Iron	99.760	96.93
	100.000	100.00

(In the second column, the figure for the summation of the elements other than iron is high, because steels which contain high carbon are usually low in silicon and manganese.)

Whenever the silicon or the manganese are increased above the usual amount (silicon from a trace to 0.50 per cent and manganese 0.10 to 1.50 per cent), a steel is produced which has properties quite different from the plain carbon steels. The steel thus made is known as an alloy steel. Among the alloy steels may be mentioned those steels which contain nickel, chromium, vanadium, tungsten, molybdenum, cobalt, titanium, zirconium, uranium, etc. Each of these elements adds some useful quality to the steel for some specific purpose.

As already mentioned, steels are made with carbon contents varying from very small amounts up to about 1.70 per cent. Heat treaters and other shop men usually speak of "points" of carbon rather than per cent. One point of carbon means one one-hundredth of one per cent (0.01 per cent) carbon. Thus a "20-point carbon steel" means a steel containing twenty hundredths of one per cent (0.20 per cent) carbon. The very low carbon steels are relatively soft and tough, but have low hardening power, and usually they are not as strong as the higher carbon steels. As the carbon content of the steel is increased the toughness becomes less and the strength and hardening capacity becomes greater.

All of the steels which have been mentioned have some particular use. There is no such thing as a "best kind of steel" unless we say that it is the best for some particular use. A steel which is the best for one job may be entirely unsatisfactory for another.

Physical Properties of Steel

Before discussing the results obtained by heat treating steel, it is necessary for us to agree on the meaning of the words used in describing the results obtained in physical testing. Many misunderstandings and arguments are due to the fact that all people do not agree on the meaning of the same words. These are given in the following paragraphs.

When we describe a man we may give his height, weight, color of eyes and hair, etc., or we may describe his character. Similarly in describing steel, we may tell what it is made of (its chemical composition) or we may describe its strength, hardness, toughness, etc. These are called the *physical properties*. We speak of the character of a man, but the properties of a material. Many methods are used in determining the physical properties of steel. A few of the most commonly used are as follows:

Tensile Strength

One of the most commonly determined of the physical properties of metals is the *tensile strength*. Tension is the act of stretching; a force causing or tending to cause extension. Tensile strength is the maximum resistance of a material to a force tending to cause extension. Tensile strength is measured in terms of unit

weight per unit cross section. (In the United States it is given in pounds per square inch.) A statement that a certain steel has a

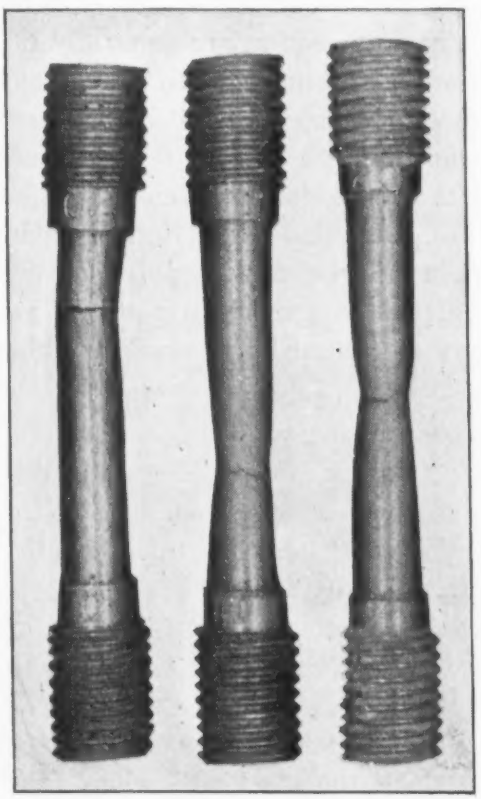

Fig. 1—Showing 3 Standard Tensile Test Bars which have been Pulled Apart in a Tensile Testing Machine.

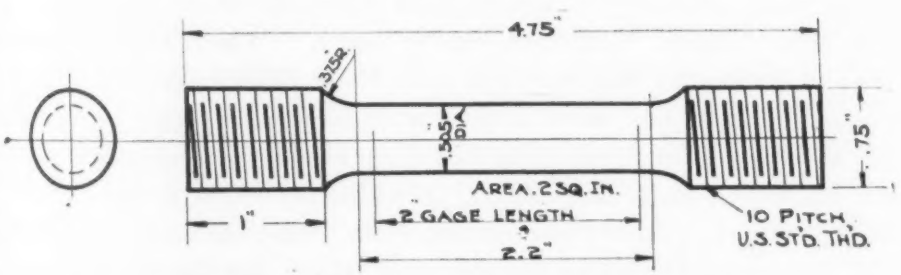

Fig. 2—Diagram Showing the Dimensions of a U. S. Standard Tensile Test Bar.

tensile strength of 50,000 pounds per square inch means that it would take 50,000 pounds to break a bar of this steel having a cross section of 1 square inch. In determining tensile strength a slow steady pull is generally used. Figures determined this way will indicate how much stationary load the steel will withstand but

will not indicate how much it will withstand under shock or vibration.

In determining tensile strength, test specimens considerably less than 1 square inch in section are generally used. Fig. 1 shows three standard tensile specimens which have been pulled apart. They originally had a diameter of 0.505 inches. The area of a cross section of one of these bars is 0.200 square inches. Fig. 2 shows a sketch of the U. S. standard tensile test bar for steel. The bar is held by the threaded ends and pulled until it breaks. The number of pounds necessary to pull one of these bars apart, multiplied by 5, gives the tensile strength in pounds per square inch. Fig. 3 shows a standard universal testing machine used in determining the tensile and compressive strengths of materials.

Another physical property which is often determined along with the tensile strength, is the *elastic limit*. When a bar of steel is given a pulling load of less than one-half its tensile strength, it stretches a little. When the load is taken off, it goes back to its original length. In this way it acts like a coil spring or a rubber band when stretched and released. As long as a body acts in this manner, it is called an *elastic body*. However, there is a limit to the amount of pull which a bar of steel will withstand without stretching and staying stretched after the load has been removed. The greatest load which the steel will withstand without staying stretched (taking a permanent set) is called the *elastic limit* of the steel. This is also reported in pounds per square inch.

In rapid commercial testing it is often easier to determine the *yield point* rather than the elastic limit. When steel is being tested in tension it stretches but very little before the load reaches the elastic limit, but when a load a little greater than the elastic limit is applied, the steel stretches very rapidly. The point where the steel begins to stretch rapidly is called the *yield point*. This is also reported in pounds per square inch. The values for the yield point are usually slightly greater than those for the elastic limit, but the two values are close enough together so that for many practical purposes they may be considered as the same.

When steel is pulled apart, it stretches more or less before it finally breaks. Different steels and even pieces cut from the same bar of steel and given different heat treatments, will stretch different amounts before breaking. Fig. 1 shows three tensile test speci-

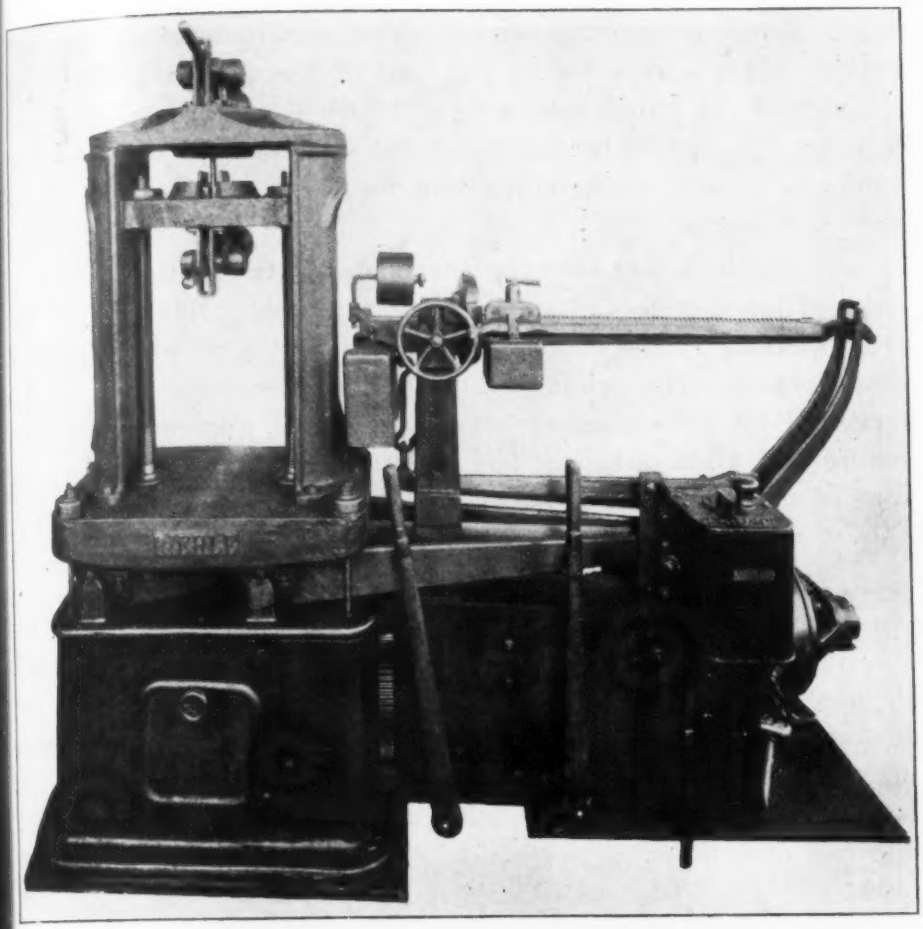

Fig. 3—Photograph of a Tensile and Testing Machine, Capable of Exerting a Load of 60,000 pounds.

mens after breaking. These bars were made from steel castings of exactly the same kind of steel. All of the specimens were the same length between shoulders before testing. Even a glance at the photograph will show that they stretched different amounts. The one on the left, which was from a casting which had not been heat treated, is very little longer than it was before it was pulled apart, that is, it shows very little *elongation* or stretch. The other specimens, which were from heat treated steel castings, showed much more elongation.

In order to measure the elongation, two prick punch marks are placed on the tensile test specimen a definite distance part (usually 2 inches), before testing. After the specimen is broken, the pieces are matched together and the distance between the

punch marks is again measured. The gain in length is the elongation. This is reported in per cent of the original length. For example if the punch marks were 2 inches apart at the start and 3 inches apart after breaking and reassembling, the gain in length would be 1 inch or the elongation would be reported as "50 per cent in 2 inches."

It will be noted that the specimens in the picture have been reduced more or less in section near the break. The areas of the cross sections at the break are less than the areas of the original cross section. The original and final cross-sectional areas are determined by measuring the specimens, with micrometer calipers, before and after testing. The difference in areas, figured as per cent of the original area, is reported as the *reduction of area.*

Limitations of the Tensile Test

The tensile test, just described, indicates the manner in which the steel will act when it is subjected to slow pulling loads. Unfortunately this test does not tell the whole story. In service, steel articles may be required to withstand sudden shocks, vibration, bending, twisting and compression, as well as slow pulls. The tensile test does not always show how the steel will act under these loads.

It is believed by some that it should be possible to figure the force of a sudden blow as so many pounds of steady pressure. For example, a three-pound weight dropped 1 foot on a spring balance will record a weight of about 50 pounds. It might be argued that the result of dropping a 3-pound weight 1 foot is the same as that of 50 pounds steady pressure. In answering this argument, let the reader say whether he would rather have a 50-pound bar of iron rested gently on his head or be hit on the head by a 3-pound hammer dropping from 1 foot above. The answer is obvious; the blow is much the worse. The same principle applies to steel. Shocks are much harder to withstand than steady loads.

There are several machines on the market which determine the amount of energy necessary to break a piece of steel by one sudden blow. These are called *impact* testing machines. The results are given in foot-pounds. The number of foot-pounds actually used in breaking the specimen is given as the impact value of the steel.

Fig. 4—
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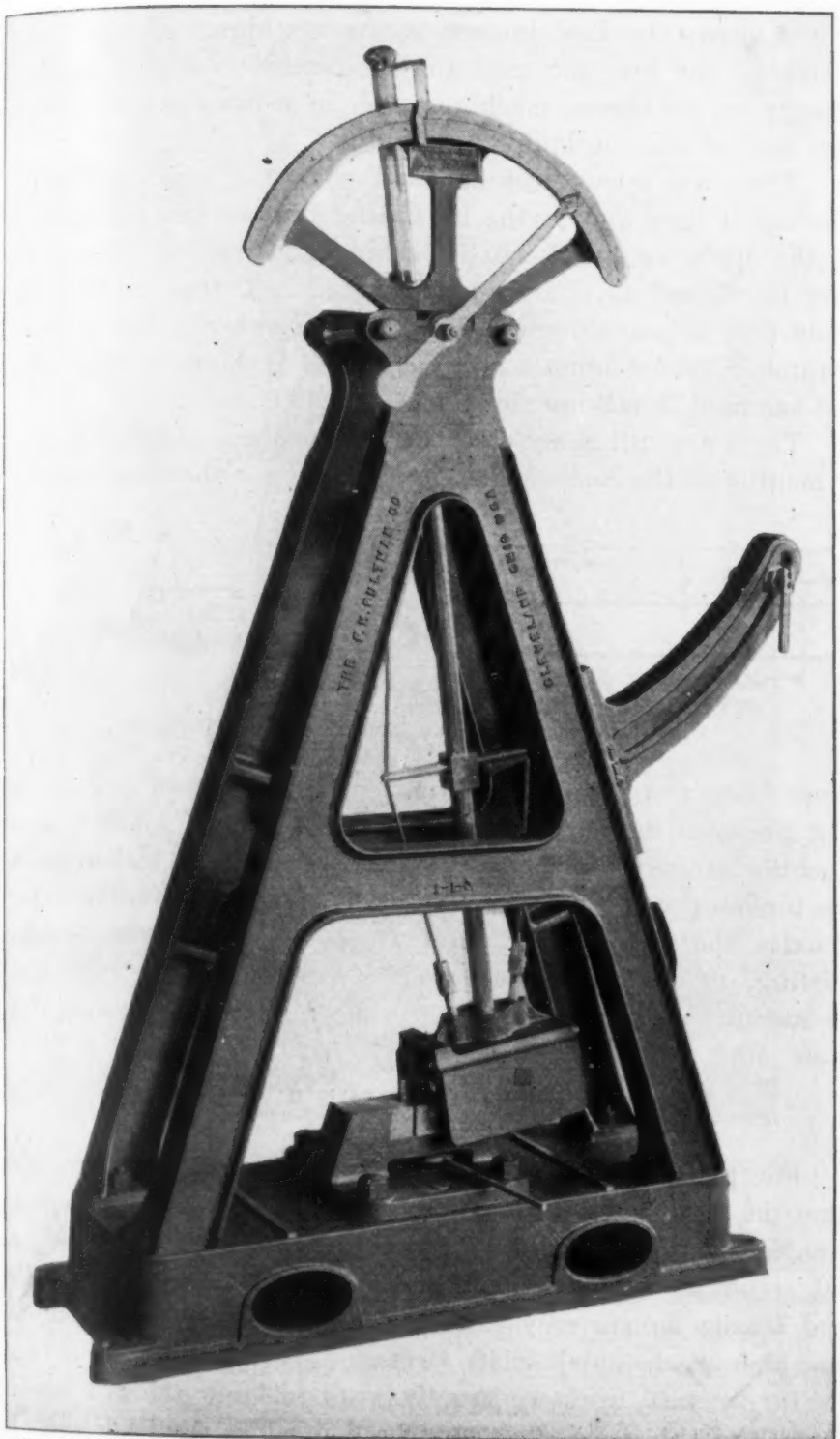

Fig. 4—Photograph of an Izod Single-blow Impact Testing Machine. The Pointer at the Upper Part of the Machine Indicates the Number of Foot-Pounds of Energy Which are Absorbed in Breaking the Notched-Bar. In this Photograph the Pendulum is Resting Against the Test Bar held in the Vise on the Base of the Machine.

Fig. 4 shows the Izod impact testing machine. Fig. 4a shows a sketch of the test bar used in this machine. Fig. 5 shows the Charpy impact testing machine. Fig. 5a shows a sketch of the test bars used in this machine.

There are other machines on the market which test steel by bending it back and forth; by hitting first on one side and then on the other; or by alternate pushing and pulling. All of these may be classed as *alternate stress* machines, that is, they apply loads first in one direction and then the other. Fig. 6 shows a Stanton repeated impact machine. Fig. 7 shows a sketch of the test bar used in making this test.

There are still many other ways of testing. Among these may be mentioned the compression, torsion and the shearing tests. The

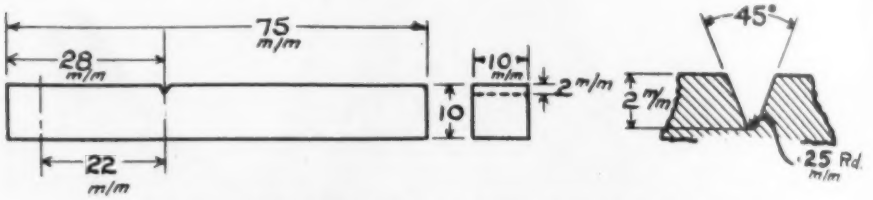

Fig. 4a—Diagram Showing the Dimensions of an Izod Test Bar.

compression test is similar to the tensile test except that the load is a pressure instead of a pull. It is used in determining the crushing strength of balls, and of castings and other articles. The torsion test is a twisting test. It is used in testing the strength of axles, shafts and other parts which must withstand torsion or twisting. The shearing test finds particular use in determining the amount of force necessary to shear off screw threads, bolts, rivets, etc.

Practical Application of Physical Tests

For practical use, it is obviously best to use the tests which come the nearest to duplicating service conditions. No one test is sufficient for determining the manner in which a given steel will stand up under all conditions of use. Steels which show good tensile figures may fail after short service when subjected to sudden shocks or alternate stresses.

In practical work we usually want to know the *safe working strength* of the steel. This may be defined as the load which the steel article will withstand without being ruined for the purpose

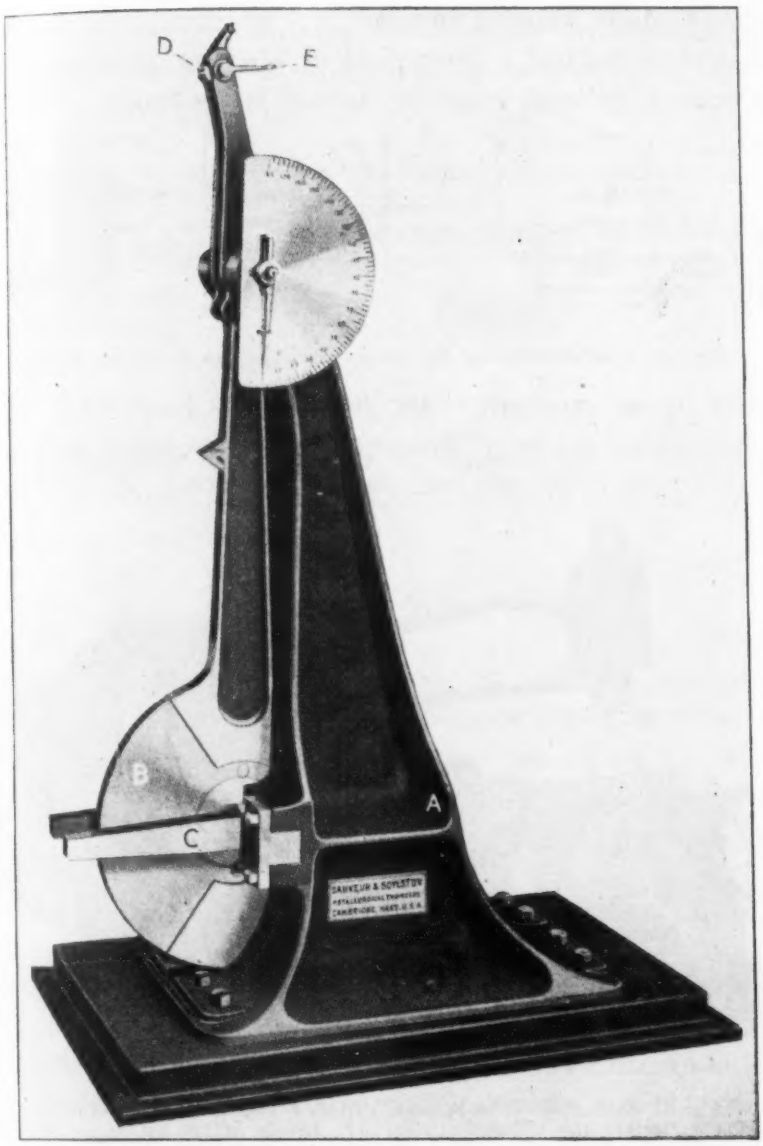

Fig. 5—Photograph of a Charpy Single-blow Impact Testing Machine. B is the Pendulum Which Breaks the Bar Held Between the Support C.

intended. Many articles may be considered as ruined, for the purpose intended, if they take a permanent set, or any other change of shape while in service. For example an automobile spring which would bend down and stay that way would be useless. Similarly a gear tooth which bent over would ruin the gear.

Another of the physical properties which is of great practical use is *toughness*. Toughness may be defined as ability to withstand

change of shape without breaking. For example a piece of steel which will withstand a great deal of bending, twisting, stretching or squeezing, without breaking, is said to be tough. This is quite

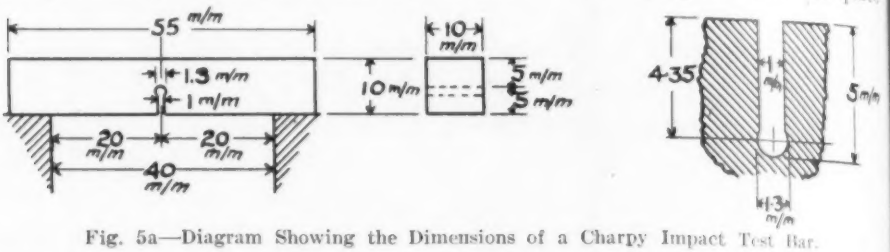

Fig. 5a—Diagram Showing the Dimensions of a Charpy Impact Test Bar.

different from strength. In fact, it is frequently true that materials which are very strong are not very tough and materials which are very tough are not usually so strong. Rubber is a very

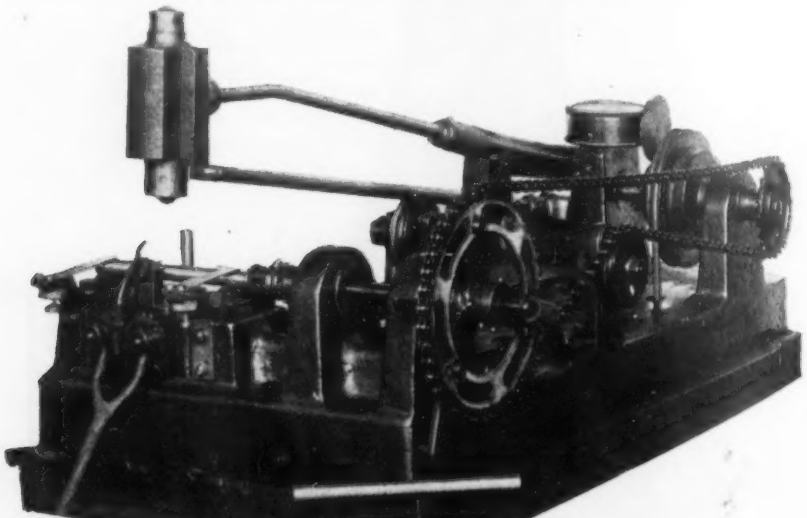

Fig 6—Photograph of a Stanton Repeated Impact Testing Machine. The Hammer Strikes the Cylindrical Test Bar and is Lifted Off of the Bar by means of the Levers. The Bar is then Turned 180 Degrees and Again Struck. The Bar is Repeatedly Struck until Failure Occurs. The Number of Blows Required to Break the Bar are Recorded.

tough material. It will permit a great deal of stretching and bending without breaking. Compared with steel, it cannot be considered strong. A rubber band will not hold as much weight as a steel wire of the same size. On the other hand glass is a very strong material. A small fiber of glass will hold more weight in proportion to its size than any other material, but it is so very brittle and withstands so little bending, that few people realize its great strength.

Both the elongation and the reduction of area in the tensile test are taken as measures of toughness, as they both show the amount of change of shape the specimen will undergo before

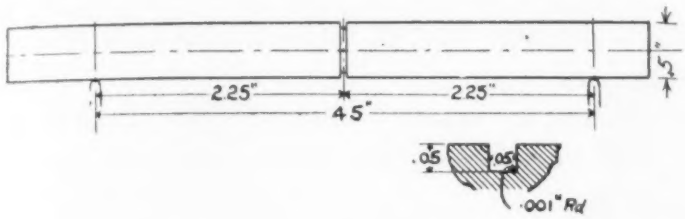

Fig. 7—Diagram of a Stanton Test Bar.

breaking. Similarly the number of degrees of twist during a torsion test, and the angle of bend in a bending test may be taken as a measure of toughness.

Hardness Tests

The heat treater is much concerned with determining the hardness of steel. Before describing the tests used in determining hardness it may be well to define what we mean by the term *hardness*. This may at first seem a simple word to define. Every one has used the words *hard* and *hardness* ever since he can remember, and yet there have been many long discussions among heat treaters and metallurgists as to what *hardness* is.

If a material cannot be scratched with a file it is usually said to be hard. Similarly if it cannot be dented by pressing a diamond or a hardened ball against it, or by hitting it with a diamond pointed hammer, it is also considered hard. Unfortunately the properties measured in the first and last tests are not the same. Some steels which are easily dented are not easily scratched, and on the other hand there are steels which resist the indenting test much better, but which are much more easily scratched with the file.

For practical purposes we frequently want to know how well the steel article will withstand a wearing action or abrasion. For example, a cutting tool is not hard enough if the edge is worn off by the rubbing action with the material it is cutting. A gear is not hard enough if its teeth are worn down by rubbing with the teeth of the other gear with which it meshes. Both of these types of failures may be classed as failures to withstand abrasion.

One good example of an article which must be hard in the way that it cannot be easily dented, is a ball bearing. The ball race must not be dented by the pressure of the balls against it. Similarly the balls must not be flattened. These parts must also be resistive to abrasion, and would be worthless if they would not resist indentation.

Hardness testing usually falls into two classes: testing resistance to wear or abrasion, and testing resistance to indentation.

Abrasion Tests

One of the oldest and most commonly used of the abrasion tests is the file test. If the steel tested cannot be scratched with a file it is said to be *file hard*. If it can be filed only with great difficulty it is sometimes described as being *just caught with a file*. If it can be filed quite easily it is said to be *file soft*. This would be an ideal test if we had a standard file, a standard way of using it, and a standard way of reporting the results. While it might not be difficult to design a machine which would always use the file the same way, that is, always take the same length stroke with the same speed and pressure, it is not so easy for a number of men to file the same way by hand. Even the same man may unconsciously make a variation in the way he uses the file. Also there is sometimes a difference of opinion as to what should be called file hard.

One of the greatest objections to the file test is that all files are not exactly alike. The hardener of the file may have small variations in his work the same as any other hardener. Then too the same file does not cut the same after it has been used, as it did when it was new.

The file test is, nevertheless, a useful shop test. It is comparatively cheap; it is rapid; and it gives a fair idea of the hardness. There are several other abrasion tests, but most of them are also hard to standardize.

Indentation Tests

Scleroscope

One of the commonly used indentation testing machines is the Shore scleroscope (Figs. 8 and 9). This instrument drops

a diamond-pointed hammer on the material to be tested and measures the height of the bounce or rebound of the hammer. A diamond point is used because a diamond is the hardest known substance. When the hammer strikes a "soft" substance it sinks in and does not rebound. It would be hard to imagine a hammer

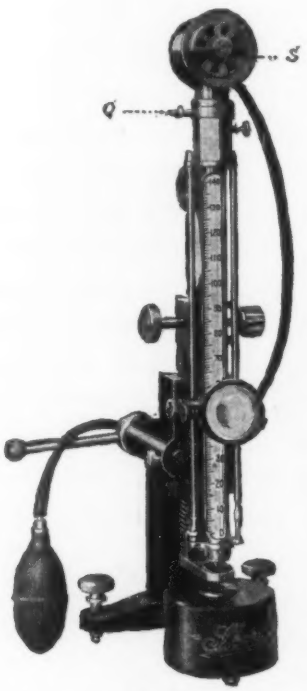

Fig. 8

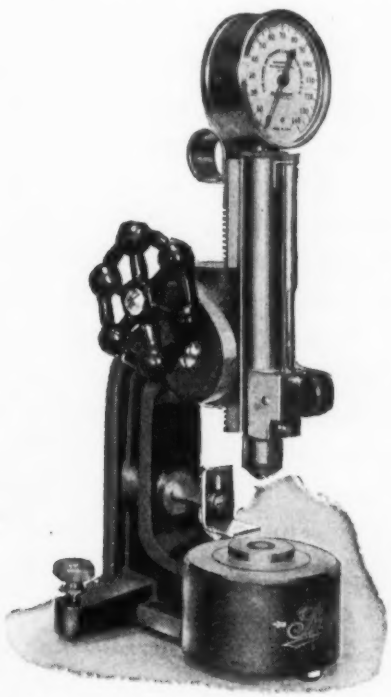

Fig. 9

Figs. 8 and 9—Photographs Showing Two Types of Shore Scleroscope. The Operator Notes the Rebound of the Hammer in the Instrument Shown in Fig. 8. The Rebound of the Hammer of the Instrument in Fig. 9 is Recorded on the Dial.

bouncing on a piece of soft butter. When the diamond-pointed hammer hits a hard material it cannot sink in very far and consequently it bounces back. The harder the material, the higher the hammer will rebound. The scleroscope is designed so that a hammer of a certain weight with a diamond point of a certain size and shape, is dropped from a certain height, falling freely through a vertical tube and hitting the piece under test. The hammer then bounces back up the tube. The highest point of the rebound is taken as the scleroscope or Shore hardness reading. There are two types of these machines (Figs. 8 and 9). In one the hammer drops and rebounds in a glass tube in the back of which is a graduated scale. The operator watches the rebound

with his eye and observes the highest mark on the scale reached by the rebounding hammer. In the other type the height of the rebound is recorded on a dial at the top of the machine. The scleroscope hardness of steel varies from about 15 to 20 for very soft steel to about 100 to 110 for the vary hard steels.

Brinell Machine

The Brinell machine also measures the resistance to indentation (Fig. 10). This machine simply presses a hardened steel ball into the metal tested. The softer the metal the larger will be the impression made by the ball. A standard size ball and a standard load should be used. Ordinarily a ball 10 millimeters in diameter (0.394 inches) and a 3000 kilogram (about 3¼ tons) load are used. The load may be applied either by means of a hydraulic press or by a system of weights and levers. Either the diameter or the depth of the impression may be measured. From the size of the impression the "Brinell hardness number" may be observed by reference to the calculated tables or be figured from Brinell's formula. The Brinell hardness of steel varies from about 120 for soft steel to about 650 to 700 for very hard steel.

Rockwell Machine

The Rockwell hardness tester also measures the resistance to indentation, by pressing a hard substance into the material to be tested. It differs from the ordinary type of Brinell machine in that the load and the "penetrator" are both smaller (Figs. 11 and 12). It measures the depth of the impression. The "Rockwell hardness number" shows directly on a dial at the top of the machine. In testing comparatively soft steel a $\frac{1}{16}$ inch diameter hardened steel ball is used as the penetrator, with a load of 100 kilograms. The readings are taken on the "B" scale of the dial. In testing hard steels a 120-degree diamond cone penetrator and a 150 kilogram load is used. The reading is taken from the "C" scale of the dial. The numbers on the dial run from 0-100.

There are several other machines on the market for testing hardness, but which will not be described. Some of these work on the Brinell principle but are more portable. Then there is the "Herbert pendulum hardness tester" which employs a heavy

pendulum swinging on a small hard ball in contact with the steel to be tested. Both the time and the distance of swinging are considered in figuring hardness.

Fig. 10—Photograph of a Brinell Indentation (Hardness) Testing Machine.

In general it may be said that the Brinell test is in common use on soft and medium carbon steels, such as forgings, castings, and automobile parts. The scleroscope probably finds greater use on hardened tool steels. Accurate Brinell readings on very hard

steels are more difficult to make. The Rockwell is a newer machine. It has an advantage over the Brinell machine in testing finished tools because it does not make a large impression in the material. Each of these machines is used for both hard and soft steels. For definite instructions for the use of the different hardness testing machines see A. S. S. T. Handbook.

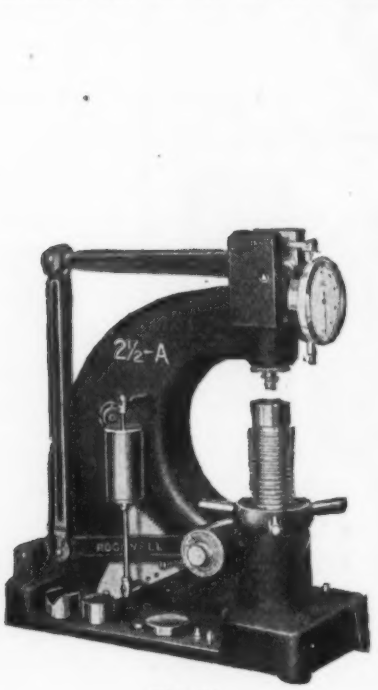

Fig. 11

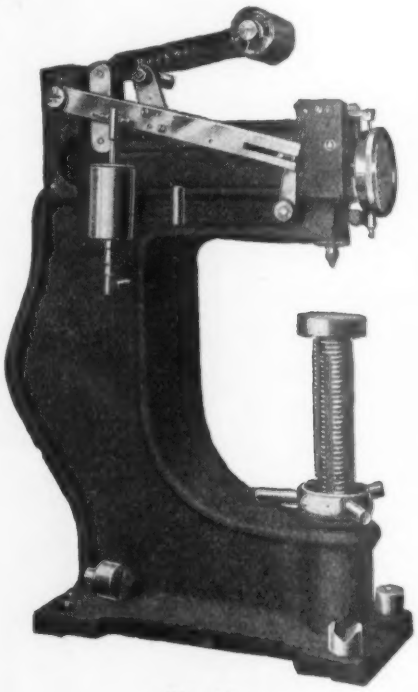

Fig. 12

Figs. 11 and 12—Photographs Showing 2 Sizes of the Rockwell Indentation (Hardness) Testing Machine.

Effect of Heating and Quenching Upon the Structure and Properties of High Carbon Steel

Before discussing the changes which take place during the heating and cooling of steel, it may be well to devote a little time to the consideration of the structure of steel. All kinds of steel and iron are made up of tiny crystalline grains. In some cases these crystals are so small that they can only be seen with the use of a high power microscope. It was once thought that some kinds of steel and iron were not made up of crystals at all. This is no longer a matter of thinking or theorizing. With the help of the microscope, crystalline grains can be seen in all kinds of steel and iron. There is, however, a vast difference in the size of the grains in the different forms of steel and iron. In fact there is a great

difference in the size of the grains in the same kind of steel, depending upon the conditions of casting, forging and heating. The size, shape and arrangement of these grains has a great deal to do with the strength, toughness and other properties of steel and iron.

Fracture of Steel.

For many years the practical man has tried to judge the size of the crystalline grains by the appearance of a fracture. When the crystal faces are too small to be seen with the naked eye or with an ordinary magnifying glass, the fracture will look smooth, "silky" or "porcelainic." When the crystal faces are large enough to be barely seen in the fracture, the broken surface, or fracture, is sometimes described as "dry" or "granular." When the crystal faces are very large and the fracture appears very rough and coarse, it is sometimes described as "coarse," "fiery" or "brilliant." The last two terms come from the fact that the fractured-surface seems to sparkle more or less in a strong light. Wrought iron has a "fibrous" break, something like wood. This may be due to the fibers of slag which run through the iron. The way in which the metal is broken has something to do with the appearance of the fracture. If it is slowly pulled apart it may look more porous or fibrous, than if it is broken with a quick snap. A piece that is broken by bending may have a different appearance on the inside part of the fractured surface near the bend, because the steel is pulled apart at the outside of the bend and compressed at the inside.

As stated before, the size of the crystalline grains has a great deal to do with the properties of the steel. In general it may be said that other things being equal, the finer the grain, the stronger and tougher the steel will be. This does not mean that a hard steel having small grains is tougher than a soft steel having large grains, but it does mean that a hard steel with small grains is tougher than a hard steel having large grains.

Hardening High Carbon Steel

For centuries it has been known that a high carbon steel may be hardened by heating it to a certain temperature or color, and then cooling it rapidly by immersing it in water. It has also been

known for centuries that certain temperatures give better results than others. If the steel is heated too hot it becomes coarse-grained and brittle. If not heated hot enough it does not harden. One of the old practical ways of determining the best temperature for hardening an unknown type of steel, was to cut a number of pieces of the steel and heat them to different temperatures or colors and then quench them in water. They would then be tested to see if they were hard enough, and would be broken, and the fracture would be examined. The temperature which would produce the greatest hardness with the finest fracture was considered the right temperature.

Metcalf Test—Showing the Effect of Heating Steel to Different Temperatures

The effect of heating steel to different temperatures, and quenching in water may be more quickly shown by heating one end of a bar of steel to a white heat and at the same time keeping the other end less than red hot. When the hottest end of the bar becomes white, the whole bar is cooled by quenching it in water. This plan of testing the effects of different temperatures was worked out by Metcalf and is now called the "Metcalf test."

For purposes of illustration, this test was run on a bar of tool steel one inch wide, ¼ inch thick and about five inches long (Figs. 13 and 14). The steel selected was a good grade of tool steel containing about 1.20 per cent carbon (120 points carbon). The bar was nicked down the center the long way, to aid in breaking at the end of the test.

One end of the bar (H) was heated to a white heat (about 2000 degrees Fahr.) [1093 degrees Cent.], while the other end (A) was kept below a red heat or probably about 900 degrees Fahr. (482 degrees Cent.). The temperature of the bar tapered down gradually from 2000 degrees Fahr. at one end to 900 degrees Fahr. at the other end, so there was some point on the bar which represented every possible temperature from 900 to 2000 degrees Fahr. Similarly all of the heat colors (dull red, bright red, orange, lemon and white) appeared somewhere on the bar. As soon as the point H reached a white heat the whole bar was quenched in water.

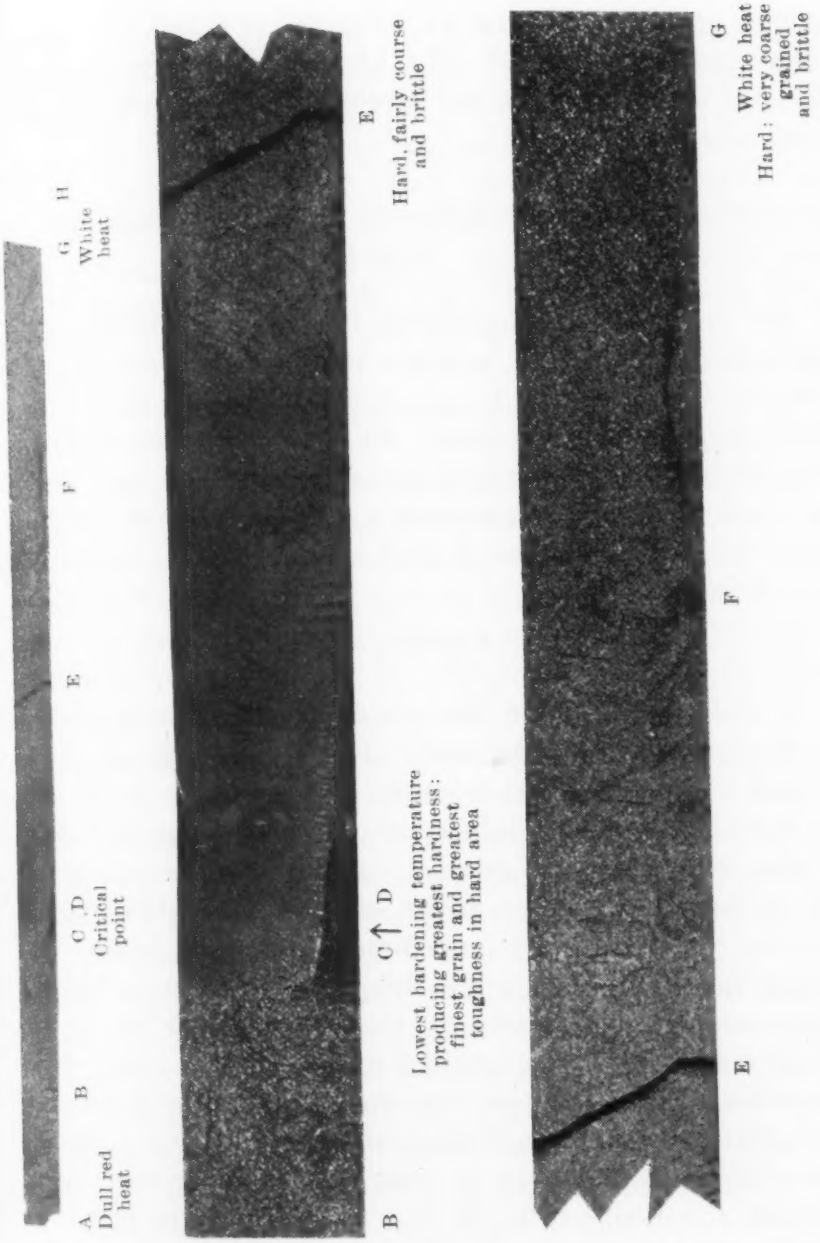

Fig. 13 **Fig. 14**

Figs. 13 and 14—Showing the Fractured Surface of the Metcalf Bar. Fig. 13 is the Full-Size Photograph. Fig. 14 is the Same as Fig. 13, enlarged 3 Times.

The bar was then tested all over with both the file and the scleroscope to determine the hardness produced by the different temperatures. The bar was placed in a vise and broken lengthwise.

The results of this test and the appearance of the fracture

are shown in Figs. 13 and 14. Fig. 13 is a full size photograph of the fracture of the bar. Fig. 14 is the same piece slightly magnified. The photographs are labeled in accordance with the following description.

Results Produced in Different Portions of the Bar from A to C

The increase in temperature from about 900 degrees Fahr. (482 degrees Cent.) at A, to about 1350 degrees Fahr. (732 degrees Cent.) or bright red at C, produced no change in the structure of the properties of the steel. The file test showed the steel to be uniformly soft and the scleroscope readings over this entire area were about 35. This portion was very tough. It required several blows of a 10-pound sledge to break it. It bent a little before breaking.

Changes at C

At the point C there was a sudden change in both the structure and properties of the steel. Just below C the steel was soft and had a coarse-grained fracture. Immediately above C it was very hard with a fine-grained fracture. The photographs show that the change is not a gradual one but appears as a sharp line. It is obvious that there can be only a small difference in the temperature of the steel immediately above or below C. It is evident, therefore, that when this kind of steel is heated to a definite temperature (shown by the point C in Figs. 13 and 14) that the steel becomes fine-grained and acquires a power to harden if quenched. This point or temperature is just as definite a point as a melting-point or a boiling-point. It is called the critical point. If steel is heated to just below its critical point and quenched, it remains soft. If it is quenched from just above the critical point it becomes hard. Different steels have different critical points. Some steels have more than one critical point. For the present we will confine the discussion to one particular steel which has but one critical point.

Changes from C to D

The portion of the bar shown from C to D was quenched from

just above the crtical point. This was the hardest and had the finest-grained fracture of the whole bar. The photographs show the grain at this place to be very smooth and silky. This portion was also the toughest place in the hard area. It was the last part of the hard area to break. It resisted the blows of a 2-pound hand hammer and had to be broken with a sledge. The scleroscope readings were 95 to 100. No higher readings were obtained anywhere else on the bar. This portion could not be scratched with a file.

Changes from D to H

As the temperature increased from D to H the crystalline grains in the steel gradually became larger and coarser. A little above E the grains are large enough to be seen with the eye, while below they keep on getting coarser until at the white hot end H, they are extremely coarse. This coarse-grained structure which is shown at the hot end of the bar is frequently called "burnt." It is not literally burnt, but is very badly over-heated.

The brittleness of the bar increased with the increase of grain-size. The hottest end of the bar was very brittle. The extreme end (G-H) broke off while the bar was being tightened in the vise (this part is not shown in the photographs). The next hottest portion was broken quite easily with a hand hammer. The bar broke crosswise at the point E.

The hardness did not increase with the increase of temperature from C-H. No place was found on the bar which was any harder than the part C-D which was heated barely above the critical point. The scleroscope readings were approximately the same (about 95) over the entire hard area. Some claim that steel which is overheated and quenched, will show a slightly lower reading than the same steel hardened from just above the critical point. No big difference was found in this case. The bar was file-hard over the entire area from C to H.

Conclusions from the Metcalf Test

The Metcalf test proves certain facts concerning the hardening of small pieces of 1.20 per cent carbon steel. These principles hold true for all of the plain carbon steels which contain more

than 0.90 per cent carbon. They will not hold true without modification for the medium and low carbon steels nor for all of the alloy steels.

1. Heating soft 1.20 per cent carbon steel to just below the critical point, followed by quenching in water, does not make any change in the structure or properties of the steel. It remains soft and has the same fracture that it had before heating.
2. Heating this steel to just above the critical point and quenching in water, produces the greatest hardness and the finest crystalline grains and the greatest toughness that can be produced by any water hardening treatment. (Oil-quenching, annealing and tempering treatments, which will be described later, produce still greater toughness.)
3. Heating to temperatures still higher above the critical point does not produce any greater hardness, but does make the steel more coarse-grained and brittle. The higher the steel is heated the more brittle and coarse-grained it becomes.

Other Changes Taking Place at the Critical Point on Heating

When a high carbon steel is heated through its critical point there are several changes which take place other than those already described. It is really changed from one kind of steel to an entirely different kind of steel. Ordinary cold steel is easily attracted by a magnet. Hence steel is usually said to be magnetic. However, when steel is heated above its critical point, the magnet has no attraction for it. Steel in this condition is entirely non-magnetic. Just below the critical point it is magnetic.

Practical Use of the Magnet

The loss of magnetic properties at the critical point has a good practical use. It has already been shown that the best method of hardening a high carbon steel is to heat it just above its critical point and quench. By testing the steel with a magnet during

heating it is possible to determine just when it passes through the critical point. Due to the fact that a magnet loses its magnetism when it gets hot, the test is made by quickly placing the magnet in the furnace and testing the steel which is being heated, and then immediately removing the magnet. If the magnet is attracted to the steel, it proves that the steel is still below the critical point. As soon as the magnet fails to be attracted to the steel, the critical point has been passed and the steel is ready to be quenched. Sometimes a bar magnet is balanced on a pivot through its center. The pivot pin is attached to the end of a long handle. When the end of the balanced magnet is held near a piece of steel which is below its critical point, the magnet dips. This makes the testing easier. Several other schemes using a magnet are also employed.

Volume Change on Heating

When steel is heated it increases in volume, but when steel passes through the critical point on heating it contracts a little instead of expanding. This will be mentioned again later in connection with the explanation of cracking during hardening.

Critical Point in Cooling

It has already been shown that when a high carbon steel is heated, it passes through a critical point where it acquires the power to harden, becomes non-magnetic, and becomes fine-grained. There is an old adage which says that "It is a poor rule that does not work both ways." This applies very well to steel. When a high carbon steel which has been heated above its critical point on heating, is allowed to cool slowly, it passes through another critical point where it loses its power to harden, and again becomes magnetic. It will be noted that the changes taking place at the critical point on cooling are just the reverse of those which took place at the critical point on heating. We might expect that the change on heating and the change on cooling would take place at the same temperature, but this is not the case. The critical point on cooling is at a lower temperature than the critical point on heating.

Explanation of Hardening

The hardening of high carbon steel by quenching may be explained by the fact, that the rapid cooling or quenching, causes the steel to pass through the critical point on cooling so fast that it does not have time to change back to the ordinary soft steel. Internal changes in steel do not take place readily after the steel is cold, so if the cooling is fast enough, the natural change back to soft steel at the critical point on cooling is prevented. In the case of the plain carbon steels, part of the changes at the critical point on cooling take place in spite of the speed of water quenching. Plain carbon steels quenched from above the critical point become magnetic again in spite of the speed of the cooling. Some of the higher alloy steels, however, remain non-magnetic after quenching. This will be discussed more fully under alloy steels.

Ac and Ar Points

So far, the critical points have been described as "the critical point on heating" and "the critical point on cooling." Use of such phrases may make the meaning clearer than the use of abbreviations, but they are rather lengthy phrases to handle. Most of the charts and much of the literature which deals with critical points, identify the points as follows:

Ac Point = Critical point on heating
Ar Point = Critical point on cooling.

The use of the abbreviations is much simpler. It is believed that the meaning is clear without stopping to explain how the abbreviations were derived.

Summary

Fig. 15 is a diagram which shows graphically the effects of several different heating and quenching treatments upon the properties of high carbon steel. This summarizes some of the points just brought out. The left hand figure in the sketch shows that when a high carbon steel is heated to below the critical point on heating (Ac point) that it does not acquire the power to harden.

If quenched from this temperature it remains soft. The next figure shows that when the same steel is heated to above the Ac point it becomes non-magnetic and acquires the power to harden. If quenched from this temperature it becomes hard. The next

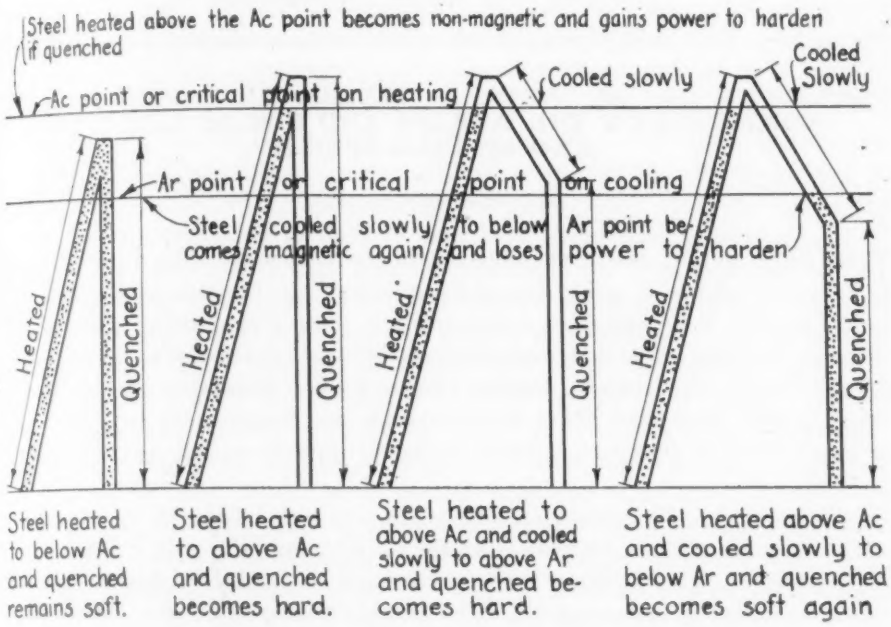
Steel heated above the Ac point becomes non-magnetic and gains power to harden if quenched
Ac point or critical point on heating
Cooled slowly
Cooled Slowly
Ar point or critical point on cooling
Steel comes magnetic again
cooled slowly to below and loses
Ar point be- power to harden
Heated
Quenched
Heated
Quenched
Heated
Quenched
Heated
Quenched
Steel heated to below Ac and quenched remains soft.
Steel heated to above Ac and quenched becomes hard.
Steel heated to above Ac and cooled slowly to above Ar and quenched becomes hard.
Steel heated above Ac and cooled slowly to below Ar and quenched becomes soft again

Fig. 15—Diagram Showing the Effect of Different Heating and Quenching Treatments on the Properties of High Carbon Steel.

figure shows that when the steel is heated above the Ac point it becomes non-magnetic and acquires power to harden. When it cools slowly to any point above the Ar point (critical point on cooling) it does not lose its power to harden. If quenched while still above this point it becomes hard. The figure on the right shows that when the steel is heated to above the Ac point it acquires hardening power and when it cools slowly to below the Ar point it changes back to soft steel. If quenched from this temperature it will be soft.

Attention is again directed to the fact that the critical point on cooling (Ar point) is a lower temperature than the critical point on heating (Ac point). This is of practical importance in both hardening and annealing and will be mentioned again in considering heat treating problems.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses

DISCUSSION OF DR. JOHN A. MATHEWS' PAPER ENTITLED "COMMENTS ON THE MAKING AND USE OF ALLOY TOOL AND SPECIAL STEELS"

By Jerome Strauss*

THE paper by Dr. Mathews published in the February, 1925, issue of Transactions affords a most illuminating survey of the development of what he has termed the "special steels" and has been prepared in an easily readable and inviting style not always characteristic of papers on technical subjects. There are, however, certain phases of his discussion of specifications which involve omissions of such importance that these must be presented to avoid a one-sided impression which is detrimental to a full understanding of the subject.

The absence of standard specifications for engineering materials and their purchase on good faith, regardless of the ability, integrity and other admirable characteristics of a producer and his personnel, leads frequently into difficulties not readily unentangled. The contract without a specification is indeed a weak agreement and the inclusion of a brand name as a substitute for the specification is sometimes meaningless. As an illustration, within a period of seven or eight years a highly reputable steel manufacturer has made four marked changes in the composition of his high speed steel without changing the brand name under which these various compositions were furnished. The producer in question was not one who manufactures only a single brand of high speed steel and has furthermore an organization for whose steel making ability and for the character and resourcefulness of whose metallurgical personnel the writer has the most profound respect. Such practices contain more of sales considerations than of technology.

Admittedly chemical composition is not satisfactory as the sole basis for the purchase of high speed steel, or of any other metallurgical product, but it is also true that physical characteristics as controlled by the character of the raw materials and the nature of the manufacturing operations is also not satisfactory as the only basis. Due weight must be given to each. Recent publications[1], [2] have indicated the importance of chemical composition and

[1] Transactions of the American Society for Steel Treating, Vol. 2, September, 1922, pages 1125 to 1154.

[2] Transactions of the American Society for Steel Treating, Vol. 4, September, 1923, pages 353 to 396.

*The author of this discussion, Jerome Strauss, is a member of the Society and is material engineer at the U. S. Naval Gun Factory, Washington, D. C.

that the ranges of composition now in use indicate the consideration given to chemical composition by the producers themselves. Furthermore, one large producer of high speed steel has since the time of publication of these references laid great emphasis upon the utility and productivity of a type composition shown therein to be exceedingly good for certain purposes and which he had previously referred to as offering insufficient advantage to justify general application; this can be construed only as appreciation of the effects of chemical composition.

Referring to the quotation from Bain and Jeffries' article it will be noted that "*small* variations in composition" are referred to as being "*relatively* unimportant." A careful perusal of the Government specification to which Dr. Mathews has reference will indicate, through the foot-note attached to the table of the permissible chemical range, that this particular portion is designed merely to indicate that high speed steel is wanted and not alloys which are not really high speed steel, but have been marketed in competition therewith. This particular table has never been employed arbitararily, and those who have provided steel under the specification are acquainted with this fact. It is, however, important that when the cutting tests have demonstrated that a certain sample is superior to others submitted, that deliveries under the contract should be made to conform within reasonable limits to the composition of this sample; Dr. Mathews has failed to state that the specification gives these limits, among which may be noted ± 0.010 per cent carbon, ± 0.50 per cent chromium and ± 0.75 per cent tungsten. These limits do not impose any hardship as evidenced by the fact that many manufacturers constantly maintain their commercial product within variations of this magnitude. The chemical requirements are therefore decidedly not without reasonable limitation and do form an active part of the purchase agreement.

As previously mentioned there are very important differences in the cutting properties and the heat treatment requirements of different compositions of high speed tool steel, among which may be mentioned the high tungsten-low vanadium type, the low tungsten-high vanadium type and the steels containing cobalt. The metallurgist using tool steels for a given purpose does not desire to carry these three steels indiscriminately through his hardening and machining operations. Each may be best for a particular purpose and set of prevailing conditions. To use Dr. Mathews' own homely quotation, if I wished to make a house look yellow, I would use yellow paint, but if I wished to paint the inside of a chemical laboratory yellow, I would be most careful to avoid the use of certain lead salts in the pigment and would consequently write a specification designating both color and chemical composition.

Undoubtedly the man with the "steel sense born of experience" has many points of advantage over one who is not so gifted, but I have seen some very serious errors made on the basis of a judgment of fracture, particularly in highly alloyed steels such as high speed steel. Dr. Mathews seems also to be surprised that users should "wish to assume a needless responsibility"; strangely enough it is only by the assumption of responsibility based upon research and experience that the user is in a position to improve his

production practice and to tell the producer just what he wants to satisfy his peculiar requirements. Not all of the larger progressive industrial establishments are purchasing tool steels on specifications free from chemical limitations. It is also necessary that one take into consideration the legal limitations surrounding Government purchases before forming an opinion in respect to the specifications employed.

I agree with the author that it has not been proven that high speed steel of one type composition is the most economical or productive under all conditions of application. I also appreciate that the Navy specification in its present state is not perfection; still, one which would be better for the purpose to be accomplished has never been seen or brought to my attention. A revision of this specification has been under consideration for some time, but I doubt seriously whether that revision will ever place "the sky as a limit" in respect to chemical composition.

While the development of new alloy steels and the improvement of older alloy steels have been largely the result of research by steel producers, nevertheless due credit should be given to the impetus created by the users of steel through pressure in the direction of more and more stringent service requirements. The user has expressed his needs in the form of specifications, and in this work the Navy has taken no inconsiderable part. Undoubtedly the knowledge and the appliances at present available are more capable of continuous reproduction of a given standard article by machining or by thermal treatment than of reproduction of steels to a given standard of composition and of that intangible "quality." To some extent at least it would seem that the latter is due shortly for improvement through more intensive research and the development of a deeper and more general understanding of the process details in steel manufacture.

DISCUSSION OF FRANCIS F. LUCAS' PAPER ENTITLED "THE MICRO-STRUCTURE OF AUSTENITE AND MARTENSITE"

By Yap, Chu-phay*

MR. Lucas' paper published in the December, 1924, issue of TRANSACTIONS certainly proved beyond a doubt that martensite is a heterogeneous mixture of two or three constituents, although it is most likely to be only ferrite and cementite. The author, therefore, believes that we can, with a clear conscience, now apply the theory of slip interference to account for the excessive hardness of martensite, whereas previously, Messrs. Jeffries and Archer attributed the hardness merely to its extremely fine-grained structure because they believed it to be a single phase.

His paper also strongly supports the contentions of Col. N. T. Belaiew regarding the structure of martensite and of austenite, which have been claimed by the latter to show a Widmanstatten structure. However, the present author cannot agree with Mr. Lucas in designating the dark, central

*The author of this discussion, Yap, Chu-Phay, member A. S. S. T., Colorado School of Mines, Golden, Colorado.

rib as troostitic, as he thinks the term should be applied to a condition of the further coagulation of cementite from the highly dispersed state in either austenite and martensite. He thinks that not only are the dark lamellæ carbide, but also the central rib running through the martensitic needle. Aside from the fact that its susceptibility to sodium picrate treatment may suggest that it is cementite, the author wishes to offer the following explanation in connection with the explanation of the causes that give rise to an acicular structure when steel is quenched from the austenitic range.

Let him first quote from a lecture on the "Birth and Growth of Crystals," by Sir Henry A. Miers, F. R. S., delivered at the Rice Institute,[1] Houston, Texas. He says:

"We invariably found that no crystals appeared in the solution until a definite temperature was reached, the liquid then being supersaturated, and this temperature was identical with that at which the denser cloud of crystals appeared in the same solution when it was stirred in the open glass trough. We entirely failed to produce any crystallization at a higher temperature. For example: a 48.2 per cent solution of sodium nitrate is saturated at 26 degrees. Below this temperature a crystal of sodium nitrate introduced into the solution will continue to grow. Above this temperature a crystal will begin to dissolve. Such a solution, when stirred in an open trough, generally produces a thin floating shower of crystals at 26 degrees, and when it cools to 16 degrees will suddenly yield quite a dense shower of crystals. Enclosed in a sealed tube, and continuously shaken, the same solution will only begin to crystallize at 16 degrees, when, as might be expected in such a strong supersaturated solution, a dense cloud of crystals makes its appearance. If a 51 per cent solution of sodium nitrate is saturated at 39 degrees, it only yields a dense shower, both in the open trough and in the sealed tube, at a temperature of 30 degrees.

"The final conclusion therefore is that a 48.2 per cent solution of sodium nitrate only begins to give birth to a few crystals at 26 degrees in an open vessel because the liquid is inoculated by crystal germs falling into it from the air; but at 16 degrees an enormous number of fresh crystals appear quite independently and, to all appearance, spontaneously. At 26 degrees the liquid, as it cools, passes from the unsaturated to the supersaturated condition in which crystals can grow, provided they are introduced into the solution from without; but at 16 degrees the liquid, as it cools, passes into a new condition in which crystals can be produced by mechanical means, such as violent shaking. Between 26 degrees and 16 degrees the solution is in what we call the metastable condition; below 16 degrees it is in what we call the labile condition. The two showers may be distinguished by the same names, the first thin shower being the metastable one and the second dense shower being the labile one. Inoculation with the minutest invisible germ is sufficient to start crystallization around the germ at any temperature below that of saturation, but inoculation of a liquid which is in the labile state produces a violent growth of needle-shaped crystals and, if it is shaken, a very dense cloud of crystals."

[1]The Rice Institute Pamphlet, 6, No. 3, July, 1919.

To quote him further:

"In ordinary experiments, the cooling liquids are not preserved from inoculation, and crystalline fragments or germs probably start the process of crystallization in the metastable state. But when the liquid becomes further cooled until it reaches the labile state, there is always a sudden and rapidly increased rate of growth, resulting in either the production of a cloud of new crystals, generally needles, or of a largely increased rate in the growth of a single crystal. My own belief is that whenever a solution crystallizes in needles, this is due to the fact that it is growing rapidly at the sides, but is advancing at its extremity into the surrounding labile solution so that it grows with great rapidity and shoots out in the form of a needle. . . . . "

Let us note that he claims that the labile condition is not reached until a 48.2 per cent solution of sodium nitrate has cooled down to 16 degrees, whereas the same condition is reached at a temperature of 30 degrees with a 51 per cent solution. Let us now turn to the work of Portevin and Garvin,[2] who found that troostite is formed at 650 degrees Cent. (1362 degrees Fahr.), and that as the speed of quenching is increased, no troostite is formed, but another transformation takes place resulting in the formation of martensite. They also found that as the velocity of quenching is increased, it becomes easier to "catch" the steel in the martensitic condition even if the temperature of quenching is not so high as is ordinarily required. In the same paper they came to the conclusion that troostite comes directly from austenite and not through martensite. The present author believes, for reasons to be stated below, that troostite can form from both austenite and martensite. Now, if we consider the troostite to be the "metastable" crystal (in the sense that Sir Miers uses it) and the martensite to be the "labile" crystal, and if we further consider the austenite as the solution, we see, therefore, the almost perfect analogy to Sir Miers' findings. Furthermore, when increasing the quenching rate, we merely hasten the cooling through the "metastable" temperature range before considerable metastable crystals are formed—in this case, troostite. The fact that it is generally easier to "catch" a steel in the martensitic condition as its carbon content increases may be accounted for by analogy to the fact that the labile temperature of a high carbon steel is higher than that of a low carbon steel. Sir Miers claims that by shaking the "labile" solution vigorously, we can produce its corresponding crystals. In the case of steel, the change in the configuration and the volume change are, so it seems to the present author, sufficient to furnish this equivalent mechanical agitation. The analogy could be extended further, but it is no longer necessary.

The author may now proceed to offer his explanation of the formation of martensite, with attendant reasons on why he believes that the central rib running through the martensitic needle is nothing but cementite, and that troostite could form from either austenite or martensite. At the time of quenching, all the metal is austenitic. Because of the sudden decrease in temperature, the whole mass is said to be supersaturated with respect to cementite (or carbon), and it must reject this excess constituent in that por-

[2]Journal, Iron and Steel Institute, No. 1, p. 469, 1919.

tion of the crystal colony where the resistance to such a rejection is least. In this connection, the author assumes the martensitic needle to be the labile crystal. The reasoning for this assumption is as follows: Martensite is well known to form twins, but Mr. Lucas' microphotographs prove that the twinning plane is generally the original octahedral cleavage plane of the mother austenite grain. If twinning takes place there, it simply means that the atoms in that portion are still far more active than those already arranged in the crystal space lattice. In other words, the kinetic energy of the former is greater than that of the latter. If its kinetic energy is higher, then it will be more mobile and thence, it becomes reasonable to believe that, because of its lowest resistance to the rejection of the excess constituent, the cementite will be rejected on the cleavage plane, forming a so-called labile solution.

The present author believes that the rejection of the excess cementite takes place first, then successively followed by the allotropic change and the further rejection of cementite along minor cleavage planes.[3] By "minor cleavage planes" the author means the cleavage planes of the smaller octahedra which build up the larger octahedra that could be seen under a microscope. The present writer measured the angles which the fine lamellæ formed with the central rib, and found them to be approximately either 60 or 30 degrees, as we find in a Widmanstatten structure of three axes. If Mr. Lucas believes these fine lamellæ to be cementite, then it would be more reasonable to believe also that the central rib is of the same constitutent.

The iron-carbon equilibrium diagram tells us that the solubility of cementite (or carbon) continuously decreases from 1.7 per cent to 0.8 per cent under normal conditions. It therefore seems to the author that the sudden decrease in temperature brought about by quenching sets up such an enormous internal tension that cementite must first be rejected. This can be easily verified by a thermodynamic examination of the system: the increase in internal energy of the system when a supersaturation exists ought to be greater than the increase due to inhibited allotropic change. The author unfortunately has no quantitative data to prove this point. The fact that troostite can form directly from austenite, as claimed by Portevin and Garvin, and as proven by Mr. Lucas from his microphotographs, is an indirect evidence that precipitation of cementite is not only independent of the allotropic transformation, but actually precedes the transformation. A close study of Mr. Lucas' microphotographs will reveal the fact that some dark lines, undoubtedly cementite, emanate from the central rib even though there were not enough stresses to cause a needle to be formed.

We can then explain the rejection of the cementite forming the central rib of the martensitic needle and the formation of the needles themselves as follows: Thus, when the steel is quenched, there is a very strong tendency for the cementite to precipitate out first, and as stated above, it is to be expected to precipitate on, and contiguous to, the cleavage planes of the mother austenite grains, on account of its higher mobility (relatively speaking) and therefore, its lower resistance to such a rejection. Because of such a rejection

[3]Lucas' microphotographs reveal portions of the martensitic needles pierced through by the cementite precipitated as lamellæ.

to this portion, the system becomes a very supersaturated system, i. e., labile. The alpha ferrite then undergoes the transformation after it has rejected its cementite (or carbon) content to the cleavage plane portion, and it cannot grow on its sides because it is continually receiving and rejecting the cementite (or carbon) passed on to it from the interior of the crystal. By the time all the excess carbon has been precipitated along the cleavage planes, it cannot grow on its sides because the crystal structure already built up by this time offers resistance to such an encroachment, and the portion adjacent to the cleavage plane being yet soft and mobile, relatively speaking, the martensite will then grow along the line of resistance and in a form that cuts down its free surface, i. e., in an acicular structure. As the rejection and the allotropic transformation take place, there is a resultant increase in the volume of the whole substance, and because of the higher mobility of the portions adjacent to the cleavage planes and because of the high dispersion of cementite in that portion,[4] the compressive stresses will be taken up by the martensitic needles, which will be warped. This is actually the case from experimental evidence.

The author is fully aware that he has defended in a modified form the amorphous theory of Rosenhain, but he believes that all in all the acicular structure of martensite may be thus explained on the basis of the rational laws governing crystal growth.

[4]Because of the high dispersion of cementite in martensite, and because of the extremely fine-grained structure of the martensite, the region originally occupied by the martensitic needles is capable of certain compression in volume. See Guertler, *Journal*, Institute of Metals, No. 2, p. 175 (1913), on the subject of the effect of the size of the aggregate on the specific volume.

NOTES FROM THE U. S. BUREAU OF STANDARDS

Nondestructive Testing of Wire Rope

PROGRESS Report No. 3, covering the investigation of non-destructive methods for testing wire rope, has recently been issued by the Bureau in mimeograph form. This report outlines the progress of the investigation up to the present time.

The study of the effect of mechanical stress on magnetic properties of steel wire has been completed, and a paper presenting the results is now on the press.

A study of the effect of wear has revealed the fact that reducing the section of steel wire by wearing off various amounts from the surface produces a change in magnetic properties which is of the same nature as that produced by the application of tensile stress. This result is in accordance with the conclusions resulting from the study of the effect of stress. Preliminary tests also indicate that the actual tensile strength of the material may be increased by wearing off part of the surface.

Work has been started on the effect of repeated stress on the magnetic properties of steel wire. This is to determine whether or not the progress of a fatigue failure is accompanied by a corresponding progressive change in magnetic properties. The results so far obtained appear to indicate that this is not the case.

Some experiments have also been made to determine whether or not alternating current methods for testing will be more satisfactory in practice than the direct current methods heretofore used.

Standard Density and Volumetric Tables

The sixth edition of circular No. 19 of the Bureau of Standards, "Standard Density and Volumetric Tables," was issued during January, and copies may be obtained from the Superintendent of Documents, Government Printing Office, at 15 cents apiece.

This circular contains standard density tables and others of a similar nature which are most often required in physical and chemical laboratories. The tables given are based on work done by the Bureau and by other investigators. In the latter case due reference is made to the author or to the publication from which the information has been obtained.

Fifty-four tables are included giving information on the density of water from 32 to 215 degrees Fahr. (0 to 102 degrees Cent.); the density of various percentages of ethyl alcohol at various temperatures; the per cent by volume and per cent by weight of ethyl and methyl alcohol solutions of known density; the density and pounds per gallon of milk and cream, and of petroleum oils; temperature corrections to the indications of hydrometers in alcohols, sugar, and sulphuric acid solutions, and petroleum oils; the relation between specific gravity and degrees Baumé for both heavy and light liquids; the relation between specific gravity and degrees A. P. I. for petroleum oils; the capacity of glass vessels as determined by the weight of water contained

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Communicated by the Director of the Bureau of Standards, Dr. G. K. Burgess.

or delivered at various temperatures; the volume of milk and cream at various temperatures occupied by unit volume at 20 degrees Cent. (68 degrees Fahr.); and master scales for the graduation of hydrometers to indicate percentages of ethyl alcohol by weight or by volume, or percentages of proof spirit.

Standard Samples

Renewal No. 12c of the standard sample of B. O. H. 0.4 carbon steel has been sent to the co-operating chemists for analysis, and it is planned to issue this sample with a provisional certificate on or before February 15.

The renewal No. 15b of B. O. H. 0.1 carbon steel is now being machined, and it is hoped that the sample will be ready for analysis by March 1.

The sample which was prepared for the renewal of cast iron No. 5 e was found to contain free graphite, and was thoroughly blown. When this was done the analyses for carbon showed too great a variation caused by difference in carbon content between the coarse and fine particles, the latter running lower in carbon. The sample is now being resieved, and the fines discarded in an attempt to produce a sample which runs sufficiently uniform.

The standard sample of bauxite ore was sent out for co-operative analysis on February 1.

Material has been received from the Electric Metallurgical Company for the preparation of standard samples of manganese metal and of high carbon ferromanganese.

Use of Iron or Nickel Crucibles for Alkali Determinations

The following brief abstract is based on a paper by Alice W. Epperson and R. B. Rudy, which was published in the *Journal* of Industrial and Engineering Chemistry, Vol. 17, page 35.

Results of tests made on two glasses and an argillaceous limestone in crucibles of iron and of nickel of the usual commercial type were comparable with those made in platinum when the mass left after the first heating and extraction was mixed with more flux and again put through the cycle of operations. If sufficient demand should arise, no doubt the preferred long tapering form of crucible would be put on the market. The life of these vessels is much less than of platinum, but those used were still serviceable after eight fusions.

Determination of Aluminum in Nonferrous Alloys

The following abstract is based on a paper by G. E. F. Lundell and H. B. Knowles of the Bureau of Standards, which was published in the *Journal* of Industrial and Engineering Chemistry, Vol. 17, p. 78.

A method for the determination of aluminum in nonferrous alloys is described, in which the usual alloying elements except phosphorus are separated from aluminum by first precipitating with sodium sulphide reagent and filtering, and then acidifying the filtrate and again filtering. The procedure is recommended for routine analysis and is not intended to replace the longer and more accurate phenylhydrazine method.

Thermal Expansion of Nickel Chromium Steels

An investigation on the thermal expansion of nickel-chromium steels has recently been started in order to obtain data on a series of commercial types of nickel-chromium steels, in both the normal and the quenched conditions. The coefficients of expansion of these steels are to be determined for various temperature ranges between room temperature and 600 degrees Cent. (1112 degrees Fahr.) This research was undertaken at the request of a large steel company.

NOTES FROM THE U. S. BUREAU OF MINES

Sponge Iron

EXPERIMENTAL work in the production of sponge iron, conducted by the Department of the Interior at the Seattle, Washington, experiment station of the Bureau of Mines, has advanced to the point where it is believed that industrial applications of the process can be safely considered for the production of sponge iron as a metallurgical reagent for the precipitation of copper, lead, and numerous other metals from solution. In those regions remote from larger iron and steel making centers and where electric energy can be had at a comparatively cheap rate, sponge iron can also be converted into iron and steel products by melting in the electric furnace.

If a piece of iron oxide is completely reduced at such a low temperature that no sintering or fusion takes place, then the piece of metallic iron formed has the same size and shape as the original piece of oxide. On account of the removal of oxygen, the structure is finely porous, exposing a large surface of iron, and the apparent density is less than that of the original piece of iron oxide. The material is called "sponge iron."

When sponge iron is used as a metallurgical reagent in the precipitation of metals from a solution, the precipitation reaction takes place with greater speed than if the precipitating reagent is a massive form of iron, such as scrap or pig iron, and hence the use of sponge iron proportionately increases plant capacity. Sponge iron is likely to be of increasing importance in the hydrometallurgy of low-grade copper and complex ores. Its production insures a permanent and reliable source of metallic iron—a very important consideration to the Pacific region, in view of the small scrap iron supply and great distance from iron-producing centers. It is probable that the future success of large-scale leaching and precipitating processes for copper and lead depends largely upon a supply of cheap sponge iron.

In the process developed through the co-operation of the Bureau of Mines and the University of Washington, almost any type of iron ore can be used for the production of sponge iron. Experiments at the Seattle station showed that similar results are obtained with magnetite, hard and soft hematite, limonite, and sintered hematite. It is probable that sponge iron will be made from such by-product materials as flue dust, pyrite cinder, various slags of high-iron content, and iron-oxide sludge.

The process developed by the Bureau of Mines consists of passing a mixture of iron ore and coal through a rotating kiln heated at one end to a temperature sufficient to convert iron oxide to metallic iron, then discharging and cooling the product and passing it through a magnetic separator to remove the sponge iron from the residual coke and siliceous material.

During the past year a furnace using the Bureau of Mines process was operated commercially at Silver City, Utah, producing about three tons of sponge iron daily. Further tests of the process on a fairly large commercial scale are much to be desired, to give the data necessary for further refinements in kiln and improvements in economy of operation.

Details of these investigations are given in Serial 2656, by Clyde E. Williams, Edward P. Barrett, and Bernard M. Larsen, copies of which may be obtained from the Department of the Interior, Bureau of Mines, Washington, D. C.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 146. ***What causes a carburized automotive ring-gear to enlarge or close up in the hole?***

The steel used was S. A. E. 1020; normalized one hour at 1700 degrees Fahr.; cooled on the floor; machined. Carburized 7 hours at 1600 degrees Fahr.; cooled in pot.

Heat treatment given was:

1650 degrees Fahr. for core; quenched in oil.

1440 degrees Fahr. for case; quenched in water—drawn in oil 10 minutes at 400 degrees Fahr.

QUESTION NO. 147. ***Is it desirable or necessary to periodically anneal the chains used on cranes? If so, why?***

ANSWERS TO OLD QUESTIONS

QUESTION NO. 134. ***What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?***

QUESTION NO. 137. ***What is the mechanism of the iodine etch for the deep etching of steel?***

QUESTION NO. 138. ***Is the electrolytic pickling process being used to show up defects in steel bars? If so, how does it compare with the regular pickling processes?***

QUESTION NO. 139. ***What is fiber, as related to forgings?***

ANSWER. **Abstract from paper by Prof. F. F. McIntosh,** TRANSACTIONS, Vol. 2, **July, 1922.**

Whether or not steel is fibrous depends largely upon the definition of the word fibrous. A long discussion might be developed on the use of the word fiber. It has been suggested that the term fiber might be used wherever the material has been extensively elongated. However, it might be well to

abandon the word fiber entirely where metals are concerned and use the word grain. The word grain would apply equally well to either cast or forged material. The objection to the use of the word grain is that it is frequently used to refer to microsructure of the metal and every effort should be made to avoid confusing the microstructure with the macrostructure.

It is not difficult to trace the fiber back through the different states of manufacture. Its study affords valuable information as to the flow and working of the metal and the castihg conditions. It shows that fiber or grain originates at the time the metal solidifies and that its character is determined by three main factors:

1. The condition of the molten metal.
2. The conditions of solidification.
3. The flow of the metal during forging, pressing or rolling.

For example, take a cross section of a 4-inch x 4-inch billet. Under examination for fiber or grain, it shows the outer ring metal resulting from the dendrite growth on the face of the mold and the corner lines and distortion due to rolling. The central zone of freezing is quite distinct. It might be likened to the trunk of a square tree with outer shell or sap wood and inner core or pith wood. The grain of the metal shows the distortion which the original ingot had received.

The grain which is so obvious in most macrographs persists through all normal working and treating of the steels. It represents an important characteristic of steels, a characteristic which is not considered as carefully as it should be by our manufacturers and metallurgists.

The chemical and micrographic conditions might not vary, but the fiber of the material, the result of melting, casting, and working conditions would vary greatly. It is desired to emphasize the fact that fiber has a marked influence on the performance of metals and that chemical, micrographic, or longitudinal tensile tests do not indicate the character of the grain or fiber of the material.

The condition of the molten metal has great influence on the fiber of the finished steel. The temperature of the metal influences the rate of freezing and size of the dendrites. The degree of oxidation has much to do with the amount of nonmetallic inclusions which collect between the branches of the dendrites. A steel which has been deoxidized in the ladle is like muddy water; all through the molten mass the reactions between deoxidizer and oxygen are going on giving nonmetallic mud which is trapped by the freezing metal and gives grain just as slag does in wrought iron. Gas in solution or trapped in the metal probably has some influence. The conditions of solidification regulate the size and character of grain through the phenomena of selective freezing. This phenomena gives the well known segregation at the top of the ingot, and it gives a similar segregation throughout the entire mass of the metal. Each crystal or dendrite as it forms follows the laws of selective freezing and results in a secondary or minor segregation or chemical heterogeneity throughout the mass of steel, a heterogeneity which persists through all heat and

mechanical treatment, a heterogeneity, which, coupled with the non-metallic inclusions, gives the fiber or grain to steel.

Regarding fiber as revealed by the macro-etch, it has been found that steel which had not yet been rolled or forged did not develop a fibrous etch, that this type of fiber was an arrangement of sonims into definite flow lines, having the appearance of fiber, these becoming a fixture immovable by heat treatment.

QUESTION NO. 140. *Can fiber be removed by heat treatment? How and to what extent?*

Answered in Question No. 139.

QUESTION NO. 141. *Does fiber exist in castings which have been subjected to mechanical working?*

Answered in Question No. 139.

QUESTION NO. 142. *What is the consensus of opinion of the cause of blisters in low and high grade steel sheets?*

QUESTION NO. 143. *How can these blisters be eliminated?*

QUESTION NO. 144. *Why do many chromium-nickel steels show a laminated structure when viewed under the microscope?*

QUESTION NO. 145. *How will the cutting qualities of a lathe tool made from an* 18 *per cent tungsten steel be affected by quenching from* 2400 *degrees Fahr. and tempered at* 1100 *degrees Fahr. as compared with a similar tool quenched from* 2300 *degrees Fahr. and tempered at* 1100 *degrees Fahr.?*

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

PROGRESS OF THE BRASS AND COPPER INDUSTRY. By W. A. Wood, consulting engineer, in *Metal Industry*, January, 1925.

The author of this article has reviewed the progress made by the brass and copper rolling mills, and tells of their future possibilities.

SMELTING SECONDARY ALUMINUM AND ALUMINUM ALLOYS. By Robert J. Anderson, consulting metallurgical engineer, in *Metal Industry*, January, 1925.

The above article is one of a series on the reclamation of all forms of scrap aluminum and aluminum alloys. Part I deals with the kinds and character of high aluminum scraps for secondary smelting.

SOME STEEL PROBLEMS IN THE DROP FORGING INDUSTRY. By Martin H. Schmid, metallurgical engineer, United Alloy Steel Co., Canton, Ohio, in *Forging-Stamping-Heat Treating*, January, 1925.

This article was presented at the Pittsburgh meeting of the American Drop Forging Institute, October, 1924, and states that close co-operation and thorough understanding between drop forger and steel producer is necessary to meet the existing demands of the consumer of drop forgings.

THE ROMANCE OF STEEL. By W. R. Klinkicht, engineer of tests, Pollak Steel Co., Cincinnati, in *Forging-Stamping-Heat Treating*, January, 1925.

The above article was presented at the Pittsburgh meeting of the American Drop Forging Institute, October, 1925, and gives a review of the manufacture of iron and steel for forgings. This paper is a historical resumé of the methods of forging from the primitive hammer to the present day steam hammer and press.

USE SODIUM FLUX FOR IRON. In *Foundry*, December 15, 1924.

This article describes a method for purifying and desulphurizing molten iron in a cupola furnace and ladle by a special flux, which has been tested in a Cleveland shop. Two sodium salts are used.

EDUCATION AND TRAINING FOR THE INDUSTRIES. In *Mechanical Engineering*, February, 1925, page 94.

One of the sessions of the annual meeting of the American Society of Mechanical Engineers, held in December, dealt with the subject of non-college type of industrial training. At this session, which was held under the auspices

of the Society's Committee on Education and Training for the Industries, chairman of which was Prof. John T. Faig, George B. Thomas, educational director of the Western Electric Company, reviewed the industrial educational work of the American Management Association and its predecessors, the National Association of Corporation Training and the Industrial Relations Association of America. Three papers were presented by Magnus W. Alexander, Frank Cushman and H. A. Frommelt, which dealt with various phases of the apprentice-training problem. It was further stated that the industry is interested in increasing the number of those receiving apprenticeship training. A co-operative system is being established for the training of metal-trades apprentices which includes principles involved in vocational training and how such training may be achieved.

PROPERTIES OF HIGH RESISTANCE ALLOYS. By M. A. Hunter and A. Jones, Russell Sage Laboratory, Rensellaer Polytechnic Institute, in *Forging-Stamping-Heat Treating*, February, 1925, page 63.

This article contains a summary of the important physical constants of the well-known high resistance alloys that are used for high temperatures.

WHEN CAN CITY GAS BE USED FOR DOMESTIC AND INDUSTRIAL HEATING? By D. J. Demorest, professor of metallurgy, Ohio State University, in *Chemical and Metallurgical Engineering*, February 9, 1925, page 233.

In the two previous articles of this series, the characteristics and economical utilization of producer gas and blue water-gas were discussed. In this paper the economic factors controlling the use of coal-gas and mixture of coal-gas and water-gas in house and factory furnaces are reviewed.

RELATION OF MATERIALS TO MACHINE DESIGN. By J. K. Wood, consulting engineer, New York City, in *American Machinist*, Vol. 61, No. 26, 1924, page 985.

The necessity for closer space limitations and higher speeds in modern machine design is bringing out the importance of the relationship of engineering materials to machine design. In this article the technical and commercial factors affecting the selection of materials are discussed, as well as the kinds of materials to be used for machine parts.

INSPECTION STANDARDS FOR STEEL CASTINGS. By W. J. Corbett, industrial engineer, Electric Steel Founders' Research Group, 541 Diversey Parkway, Chicago, in *Iron Age*, January 8, 1925, page 115.

The above article states that the manufacture of steel castings has been characterized during the last 10 years by many important developments. Among these is the matter of exacting specifications, to which engineers of tests of large railroad systems and metallurgists connected with the steel casting industry, began to give serious attention in 1916, in an effort to safeguard purchasers of cast steel parts used in railroad equipment. A group of five companies, known as the Electric Steel Founders' Research Group, has undertaken the investigation of standard specifications for steel castings.

HIGH TEMPERATURE INSULATION. In *Iron Trade Review*, January 8, 1925, page 151.

Millions of dollars are being lost to American manufacturers because valuable heat is allowed to escape from industrial furnaces. High temperature insulation offers a means of partly stopping this condition. The above article, which deals with the elementary phases of furnace insulation is from a lecture prepared for educational purposes by the Celite Products Company of Chicago.

THE HEAT TREATMENT OF STEEL CAMS. By J. K. Wood, consulting engineer, New York City, in *American Machinist*, January 8, 1925, page 47.

The above article states that there are severe requirements on materials used in cams, and discusses carburizing and non-carburizing steels and their heat treatment. The advantages of alloy steels for certain types of cams are discussed.

WEAR OF REDUCTION-GEAR TEETH MEASURED FROM PLASTER CASTS. By H. B. Chapman, manager steam marine division, Westinghouse Electric and Manufacturing Company, in *American Machinist*, January 8, 1925, page 51.

This article tells how an accurate cast of a helix or tooth can be made, and the method used serves to keep a complete record of reduction gear wear.

CONTROLLING MOISTURE IN SAND. By A. A. Grubb, Ohio Brass Co., Mansfield, Ohio, in *Foundry*, February 15, 1925, page 145.

A paper dealing with the reclamation of molding sand by A. A. Grubb and F. A. Wolf, which was presented at the Milwaukee convention of the American Foundrymen's association, 1924, and which was abstracted in a previous issue of *Foundry*, described a number of important tests and showed how mulling increases the bond of cheap sand, refuse, reclaimed and new sand mixtures. The large number of inquiries received by the author, asking for details concerning the apparatus and methods used in testing the sand led Mr. Grubb to write this article. In it he describes the apparatus and the methods of procedure in the rapid determination of sand quality. It is also pointed out that temper influences the bond, permeability and gas content of sands.

AIR-HARDENING STEELS. By J. K. Wood, consulting engineer, New York City, in *American Machinist*, February 12, 1925, page 265.

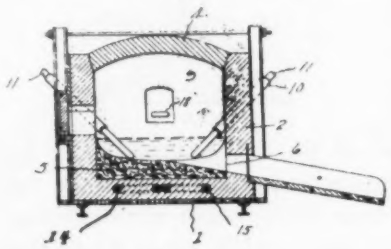
In this article the author discusses the microscopic constituents of iron and steel, their behavior under heat treatment, the constitutional diagram and results of alloying. The advantages of air-hardened steels with varying alloy content are covered.

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,514,102, Process of Treating Metal, Richard Robinson, of Masury, Ohio.

This patent describes an electric furnace and the process of using the same, comprising a base 1, side walls 2 having a discharge outlet 6, a lining of heat resisting material 5, top 4, electrodes 11 projecting into the furnace and electro-magnets 14 and 15 embedded in the base of the furnace below the ends of the electrodes. In the use of the furnace, the electrodes are inserted through the slag and below the bath of molten metal, and the heating is carried on in this way. The flux from the electro-magnets deflect



the current between the electrodes, producing a whirling vortex motion which prevents segregation in the bath. At the start of the operation, the materials to be melted are charged into the furnace and preferably melted are partially melted by means of gas or oil burners 18. A coating of slag is formed over the top of the metal to prevent the same from oxidization and the electrodes 11 are pushed through the holders 10 below the surface of the metal and with their ends approximately over the center of the electro-magnets 14, whereupon the electric current is turned on and the melting and purifying of the metal is proceeded with.

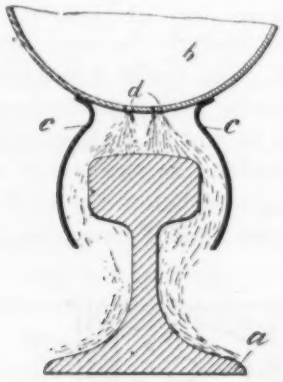
1,516,157, Method of Hardening Iron, Donald McCormick Scott, of Rochester, New York, assignor to the T. H. Symington Company of New York, N. Y., a corporation of Delaware.

This patent relates particularly to the forming of a hard wear-resisting surface on a malleable iron casting without demalleabilizing the adjacent metal. In carrying out the process, the decarburized surface produced by the annealing of the malleable casting, is cleaned by machining or grinding and this surface is heated sufficiently to cause the graphitic carbon to change to a free state and go back into solution forming a compound with the iron which is allowed to cool in a normal way. To prevent demalleabil-

ization in the entire section, the portions surrounding and at the back of the portion being hardened, are artificially cooled by water or other cooling fluid to prevent a rise in temperature thereof.

1,516,407, Manufacture of Railway and Tramway Rails, Christer Peter Sandberg, of London, England.

This patent describes an apparatus for differential cooling on a railway rail, and preferably provides a device which will cool the top of the rail and at the same time the areas of large cross section at the juncture of



the web with the head of the rail and with the base. The preferred embodiment of the invention comprises a pipe or tube "b" provided with openings "d" in the base thereof and with shields "c" which will direct the air or other cooling fluid which issues from the openings "d" around the head and flange of the rail and out along the base "a" to cool the same.

1,517,451, Heat Treatment of Manganese Steel, Welsley G. Nichols, of Chicago Heights, Illinois, assignor to American Manganese Steel Company, of Chicago, Illinois, a corporation of Maine.

This patent describes the process of heat treating manganese steel castings. According to the inventor, it has heretofore been considered necessary to have the furnace and the castings at the same temperature when the castings are charged into the furnace, thereby making it necessary either to permit the furnace to cool to the temperature of the castings or to shake out the castings and charge them while still quite hot into the furnace, causes an unnecessary loss of time, and to charge the castings while they are still hot into the furnace causes additional expense and a great amount of discomfort to the workmen. This inventor has discovered that the castings may be properly treated by introducing the castings at low or atmospheric temperature into a furnace standing at a relatively high heat but with an interruption of the heat source, permitting the temperature of the furnace to fall as the castings absorb heat therefrom and thereafter generating heat in the furnace and raising the temperature in that required in the heat treatment.

News of the Chapters

STANDING OF THE CHAPTERS

IN the February issue of TRANSACTIONS appeared the relative standing of the 29 chapters of the Society as of December 1, 1924 and as of January 1, 1925. The tabulation which appears below shows the membership standing of the chapters on February 1, 1925. For the convenience of ready comparison, the standing as of January 1, 1925, is included. It will be noted that there are two changes in Group I, only one change in Group II and several in Group III.

Standing as of January 1

I	II	III
1. Detroit (278)	1. Hartford (131)	1. TRI CITY (60)
2. CHICAGO (273)	2. Lehigh Valley (115)	2. New Haven (53)
3. CLEVELAND (267)	3. Golden Gate (103)	3. LOS ANGELES (53)
4. Pittsburgh (262)	4. Milwaukee (78)	4. ROCHESTER (53)
5. Philadelphia (247)	5. Syracuse (75)	5. Washington (49)
6. Boston (221)	6. Cincinnati	6. Worcester
7. New York (201)	7. Indianapolis	7. ROCKFORD
	8. Buffalo	8. Schenectady
	9. North West	9. South Bend
	10. St. Louis	10. Providence
		11. Springfield
		12. Toronto

Standing as of February 1

I	II	III
1. CHICAGO (275)	1. Hartford (128)	1. Tri City (59)
2. Detroit (274)	2. Lehigh Valley (117)	2. LOS ANGELES (55)
3. Cleveland (272)	3. Golden Gate (104)	3. Rochester (54)
4. Pittsburgh (265)	4. Milwaukee (79)	4. New Haven (52)
5. Philadelphia (250)	5. Syracuse (73)	5. Washington (49)
6. Boston (216)	6. Cincinnati	6. Rockford
7. New York (203)	7. Indianapolis	7. Worcester
	8. Buffalo	8. Schenectady
	9. ST. LOUIS	9. PROVIDENCE
	10. North West	10. South Bend
		11. Springfield
		12. Toronto

Quite an interesting race is developing between the chapters in Group I. There are only two changes from the standing of the chapters since the last report, but the exact numbers vary somewhat when based upon the addition of new members, and those lost by non-payment of dues.

BOSTON CHAPTER

THE Boston chapter of the American Society for Steel Treating held a meeting on February 20 at the Worthington Pump and Machinery Corporation, Cambridge. From 3:30 to 5:00 p. m. inspection of the various departments of the company was made. Dinner was served at 6:00 p. m. in the dining room of the plant. At 7:00 p. m., Henry Brewer of Leeds and Northrup Co., Philadelphia, addressed the meeting choosing for his subject, "The Use and Abuse of Pyrometers and Some Methods of Checking." As an additional feature, J. L. Yates, of the Worthington Pump and Machinery Corporation, continued his talk which he presented last year on "Deisel Engines."

The March meeting of the chapter will be addressed by Henry Voltmann of the W. S. Rockwell Company, who will speak on the subject of "Furnaces." A. V. deForest of the American Chain Company will present a paper at the April meeting on the subject of "Magnetic Testing of Steel." At the May meeting, F. R. Palmer, of the Carpenter Steel Company, will speak on "Troubles Encountered in the Design, Applications, and Treatment of Steels, and Their Practical Solutions."

BUFFALO CHAPTER

The Buffalo chapter of the Society held a meeting on January 26 at the Hotel Buffalo, which was called to order at 8:00 p. m. by Chairman Armstrong. The minutes of the July 9 meeting were read and approved. The meeting was then opened for discussion, the following subjects being discussed: manganese castings; malleable iron hardening; welding of high speed steel blades to low carbon backs for shear knives, and heat treating high speed steels. The meeting adjourned at 10:15 p. m., 14 members and 7 guests being present.

CHICAGO CHAPTER

On February 12 the Chicago chapter of the Society held a meeting at the City Club. Dinner was served at 6:15 p. m., and at 7:00 p. m., H. P. Donavan, representing the C. M. Postl Health Club, gave a short, snappy talk on "Physical Culture, and its Relation to Business Efficiency." The meeting began at 7:30 p. m., the first speaker of the evening being Dr. Zay Jeffries, Aluminum Company of America, who gave an illustrated talk on "More about Steel." W. S. Bidle, president of the Society and president of the W. S. Bidle Company, told about the activities of the Society. W. H. Eisenman, secretary, was the third speaker of the evening, who spoke of the progress of the Society, and likewise told of his trip out west.

CINCINNATI CHAPTER

The February 12 meeting of the Cincinnati chapter of the Society, which was held at the Ohio Mechanics Institute, was addressed by A. H. d'Arcambal, chief metallurgist with the Pratt and Whitney Co., Hartford. The

subject of his paper was, "Carbon Tool and High Speed Steels Used in the Manufacture of Small Tools," being illustrated with lantern slides and a number of samples of both good and defective tools. A lively discussion followed the presentation of this paper.

CLEVELAND CHAPTER

The regular monthly meeting of the Cleveland chapter of the A. S. S. T. was held on Friday evening, February 20, 1925, at 8:00 p. m. in the rooms of the Cleveland Engineering Society, Hotel Winton. For this meeting the program committee secured Sam Tour, metallurgist, Doehler Die Casting Co., Batavia, N. Y. ,as the speaker. Mr. Tour presented a paper on the subject of "Salt Baths," and as this is the subject on which he is a recognized authority, he was able to cover it in a rather brief yet comprehensive way. Mr. Tour emphasized and elaborated upon the important points mentioned in his published papers, and also discussed the most recent developments in the control and operation of fused salt baths. The questions of proper furnace design and furnace operation are very often not carefully enough considered according to Mr. Tour. These questions are fully as important as that of the chemical composition of the bath. The speaker advocated the use of larger furnaces than are commonly built and also plenty of insulation. Electric heating was recommended, provided the furnace is especially designed for the needs of the user and when electric power can be purchased at a reasonable price. Mr. Tour showed a number of lantern slides to illustrate his remarks in regard to furnace designs, various compositions of salt baths and the pitting and decarburization of the steel tools or parts. His paper, as might be expected, brought out considerable discussion. About eighty members and guests were present at this meeting. A number of members and guests who met together preceding the meeting were served with an excellent dinner in the hotel dining room at 6:45 p. m.

DETROIT CHAPTER

The Detroit chapter of the American Society for Steel Treating held a meeting on February 16 on the 15th floor of the General Motors Building. The subject of "Hardness Testing" was discussed by C. E. Hellenberg, Wilson-Maeulen Company, and H. A. Weaver of the Steel City Testing Laboratory. Mr. Hellenberg, being an authority on the uses, operation and service requirements of the Rockwell hardness testing machine, gave a very capable presentation and had some interesting data on special applications of this machine. Mr. Weaver discussed the principles and uses of the Brinell machine, with which he has had years of experience, and gave some interesting practical information. Dinner was served at 6:30 p. m.

GOLDEN GATE CHAPTER

The January meeting of the Golden Gate chapter took place January 14 at the New Peerless Cafe in Oakland. The first event of the evening was the second of the series on steel, namely, "The Open Hearth Furnace," by H. S.

Taylor, chief metallurgist of the Holt Manufacturing Company, which was illustrated by slides of many different types of steel-making furnaces.

The second event was a talk on heat treating methods at the Hall-Scott Motor Car Co.'s plant by J. C. Straub of that company.

Both talks were well received and elicited much discussion, and the evening was an undoubted success.

A most successful and enthusiastic meeting of the Golden Gate chapter of the A. S. S. T. was held Saturday night, February 14, at the Engineers Club. The meeting was well attended, there being over sixty present. The first event on the program was a lecture on "Recalescence and Decalescence Points of Steel" by Dr. W. J. Crook, consulting metallurgist, Pacific Coast Steel Company. His very difficult subject was handled with masterly simplicity by the assistance of many charts and diagrams, and formed a most interesting link in the chain of the series on "Steel" that has been undertaken by the chapter. The talk was also illustrated by the projection of metallographic slides of high magnification by a special piece of apparatus, kindly loaned for the occasion by Messrs. Spindler & Sauppe.

Major Brett of the U. S. Army Ordnance made a few remarks concerning the work that is being done by the army in educating the various steel industries for mobilization during war time.

The program then continued with a talk on "Grain Structure" by Fred L. Wight of the U. S. Steel Products Company. This consisted of a number of large slides, illustrating grain structure, resulting from various correct and incorrect heat treatments. It was really an account of a number of different problems such as every steel manufacturer has to solve, and formed a very excellent and practical illustration for the talk on the iron-carbon diagram.

The evening closed with a vote of thanks to the speakers for their most interesting and instructive talks.

HARTFORD CHAPTER

F. R. Palmer of the Carpenter Steel Company, addressed the February 10 meeting of the Hartford chapter of the Society, which was held at the Hartford Engineers' Club. The title of Mr. Palmer's paper was "Giving Steel Tools a Chance." In a very interesting and non-theoretical way he brought out the idea that a tool failure is not due to any one cause, but that the stresses causing ultimate failure are a summing up of the effects of all of the processes through which the tool passes from ingot to the ultimate use. To get the best results with the least number of failures, care must be exercised in the design of tool, selection of a steel for quality, heat treatments, before and after machining, and grinding. Lantern slides illustrated the characteristic failures from various improper treatments. This was a very practical talk and many interesting points were brought out in the discussion which followed. The meeting was preceded by a dinner at the University Club.

INDIANAPOLIS CHAPTER

On February 9 the Indianapolis chapter of the Society held a meeting in the Y. M. C. A. auditorium, at which time an illustrated lecture with motion

pictures was presented, entitled "The Manufacture and Heat Treatment of Die Blocks." This was shown through the courtesy of the Heppenstall Forge and Knife Company of Pittsburgh, and was discussed by G. O. Desautels, representative of the company. Many interesting questions were answered following the presentation of the film. Dinner was served at 6:30 p. m.

LEHIGH VALLEY CHAPTER

The Lehigh Valley chapter of the American Society for Steel Treating held a meeting on February 20 in the Easton Public Library. The speakers for this meeting were G. R. Hanks, general superintendent, and John Hall, metallurgist, Taylor-Wharton Iron and Steel Co., High Bridge, N. J., who discussed the subject of "Manganese Steel."

NEW HAVEN CHAPTER

On Friday, February 13 the New Haven chapter of the Society held a meeting at the Winchester Club House, at which time A. V. deForest, research engineer with the American Chain Company, presented an interesting paper entitled, "Magnetic Testing of Steel." This talk was followed by two reels of moving pictures loaned through the courtesy of the Bureau of Mines. Reel 1 was entitled, "Alloy Steel," and Reel 2, "Heat Treatment of Steel."

NEW YORK CHAPTER

The February 11 meeting of the New York chapter, which was to have been addressed by Dr. Carl Benedicks of Sweden, was postponed, inasmuch as Dr. Benedicks did not arrive in America in time for this meeting.

NORTH WEST CHAPTER

The North West chapter of the American Society for Steel Treating held a meeting on February 10 at 8:00 p. m. in the Manufacturers' Club of Minneapolis, at which time W. S. Bidle, president of the W. S. Bidle Company of Cleveland and president of the Society, discussed some problems of heat treating small tools and forgings. W. H. Eisenman, secretary of the Society, was also in attendance at this meeting and spoke of the progress of the Society since its organization. An informal dinner was served at the Elks' Club at 6:00 p. m.

PHILADELPHIA CHAPTER

The Philadelphia chapter of the Society held a meeting on January 30 in the Engineers' Club. The first paper of the evening was given by H. A. Schwartz of the National Malleable Steel Castings Company of Cleveland and was entitled, "Malleable Cast Iron." The second feature was a motion picture accompanied by a talk on the "History, Manufacture and Applications of Manganese Steel," which was given through the courtesy of the Taylor-Wharton Iron and Steel Company of High Bridge, N. J.

The chapter held a meeting on February 20 in the Engineers' Club, at which time "The Hardening of Steel" was discussed by R. S. Archer, research metallurgist with the Aluminum Company of America. This subject, which is one of first importance to steel treaters, was very well received. Dinner was served at 6:30 p. m. preceding the meeting.

PITTSBURGH CHAPTER

The February meeting of the Pittsburgh chapter was held in the assembly room of the Fort Pitt Hotel on the evening of the 3rd. The U. S. Bureau of Mines motion picture entitled, "The Story of a Watch," was shown from 7 to 8 o'clock. At 8 o'clock a short business session was held, after which the speaker of the evening was introduced, Dr. V. N. Krivobok, who is research associate of the Metallurgical Research Bureau at the Carnegie Institute of Technology.

The subject of Dr. Krivobok's talk was, "Some New Facts in Regard to Dendritic Segregation." In a series of photomicrographic slides, he showed how the dendritic structure in iron and steel in the cast condition persisted in spite of heat treatment, not only as usually applied, but even of a more drastic nature. Photomicrographs of plain carbon steel, high carbon tool steel, high speed steel, manganese steel, nickel steel and stainless steel were shown both as cast and as annealed. In all cases the annealing failed to break up the dendritic structure. By etching martensitic steel with tincture of iodine, he was able to show the dendritic pattern.

Dr. Krivobok then showed by photomicrographs that cold working failed to break up this structure but rather elongated or distorted it. In his further remarks he stated that he had found the dendritic structure to persist to a very noticeable degree in hardened high speed and high carbon tool steels.

In answer to the question as to what elements were most apt to cause a dendritic structure, Dr. Krivobok described the inability of carbon to remain in areas in which phosphorus was segregated, and because of this fact named phosphorus as one of the elements most apt to cause dendritic structure. He also remarked that although the analysis of a steel might be 0.05 per cent phosphorus, it does not follow that phosphorus would be evenly distributed throughout the steel, but that this element is more or less segregated causing certain areas to contain a great deal more phosphorus than the analysis indicated. This condition would cause the carbon to be expelled from the phosphorus areas, thereby causing soft spots. Dr. Krivobok then illustrated with some photomicrographs how breaking or rupture occurred through the medium of slips which were traced back to planes of dendritic structure.

At the conclusion of his talk, Dr. Krivobok showed specimens of fractures occurring between dendrites.

In the general discussion which followed, many questions pertaining to methods of breaking up this dendritic structure were asked, but Dr. Krivobok was of the opinion that the best method was to eliminate the causes in the steel making and made several suggestions that might be of benefit.

The large attendance and lengthy discussion proved Dr. Krivobok's talk to be of great interest.

ROCHESTER CHAPTER

On December 8, 1924, the Rochester chapter of the Society held a meeting, at which time W. R. Pafenbach, sales manager of the Simonds Saw and Steel Company of Lockport, N. Y., spoke on "Steel Mill Practice and Its Relation to the Finished Product." Some mill difficulties and their solutions, unusual cases of decarburization and methods of forming sound billets were among the interesting problems and processes discussed. "Rare Metals, Tungsten, Molybednum and Tantalum" was the subject of Dr. C. W. Balke's talk at the January 12 meeing of the chapter. Dr. Balke is director of the research department of the Fansteel Products Company. A very thorough talk was given on the preparation and uses of these rare metals. Tantalum and its uses in radio aroused a lively discussion. All radio enthusiasts are acquainted with the Balkite rectifier. On February 12 the chapter meeting was addressed by S. C. Spalding, chief metallurgist of the Halcomb Steel Company. His intensely interesting lecture on "Tool Steel, Why Did It Break," was very enthusiastically received. Cracks caused by punch marks, sharp angles, and grinding were illustrated, and remedies to eliminate them, were offered. There has been a very good attendance at the monthly dinners held preceding the meetings.

SPRINGFIELD CHAPTER

The Springfield chapter of the Society held their regular monthly meeting on February 24 in the Chamber of Commerce Rooms. A motion picture supplied through the courtesy of the Bureau of Standards and entitled, "The Story of Alloy Steel," and also a film on "Transportation" was the feature of this meeting.

ST. LOUIS CHAPTER

The regular monthly meeting of the St. Louis chapter was held on Monday evening, February 16, at the American Annex Hotel, at which time J. M. Watson, metallurgical engineer, Hupp Motor Corporation, Detroit, presented the Bureau of Mines motion picture, showing the heat treating department at the Hupp Motor Plant. After the picture Mr. Watson answered many questions and went into many details of the various operations and practices followed. Attendance at this meeting broke records of all former meetings this year, and the dinner preceding the meeting was also very popular with about 35 members attending. The program for the coming meetings was announced. The annual visit of the national officers of the Society is on March 30; the American Rolling mills picture in April; and the Hump Method of Heat Treating in May. The March meeting will include a talk by President Bidle on "The Most Important Things in Heat Treating," and W. H. Eisenman, National Secretary, will have an interesting talk on the progress of the Society work. Mr. Bidle's talk is the result of 30 years experience in the heat treating field.

SYRACUSE CHAPTER

The February 16 meeting of the Syracuse chapter of the Society held at the Onondaga Hotel, was addressed by Sam Tour, metallurgist with the Doehler Die Castings Co., Batavia, N. Y., on the subject of "Die Castings." Dinner was served at the University Club at 6:30 p. m.

TRI CITY CHAPTER

The subject of "Oxyacetylene Welding and Cutting" was discussed by George Rose, service engineer of the Oxweld Oxyacetylene Company, at the January 22 meeting of the Tri City chapter of the Society, which was held at the Le Clair Hotel, Moline. Mr. Rose's talk was illustrated with motion pictures. These pictures were highly educational, showing typical welding and cutting jobs and technique. Dinner was served at 6:45 p. m.

The February 13 meeting of the chapter was held at the Davenport Chamber of Commerce, and was addressed by W. S. Bidle, president, and W. H. Eisenman, secretary of the Society. Mr. Bidle's talk was entitled, "The Most Important Things in Steel Treating," which involved to a great extent many kinks in heat treating that he has acquired in this important industry. Mr. Eisenman outlined in a general way the activities of the Society and gave first hand information as to the activities of the various chapters.

WASHINGTON CHAPTER

The Washington chapter of the Society held a meeting on February 20 in the auditorium of the New Interior Department Building. "The Manufacture of Some Special Alloy Steels" was the subject of a paper presented by Marcus A. Grossmann, metallurgical engineer with the United Alloy Steel Corp., Canton, Ohio. This was the third of a series of talks dealing with the alloying elements in steel. Ferro-alloys and structural steels have previously received consideration. Mr. Grossmann reviewed present practice in the alloy tool steels, including in his talk all of the important combinations other than high speed steel, which will be the subject of a later meeting.

WORCESTER CHAPTER

The Worcester chapter did not hold a meeting in January due to difficulty in arranging for a speaker, but the delayed meeting was held February 5 at the University Club, 377 Main Street. Dr. Langenburg, research engineer of Watertown Arsenal, was scheduled to speak on "Quenching Media," but was unable to come due to illness.

His place was taken by Dr. Lester of the Watertown Arsenal, whose talk on X-ray application to steel castings proved very interesting to the 42 members and guests who attended.

Dr. Lester said that the failure of so many steel castings used in ordnance and ammunition during the war led to the use of the X-ray for the location of hidden defects.

The application of the X-ray was not merely for inspection purposes so that the defective castings could be rejected, but was intended to locate the defects and show their cause so that methods of manufacture might be improved and the defects might be eliminated in the future.

Dr. Lester explained the construction and operation of the Coolidge X-ray tube and the methods employed in its application.

The X-ray is also used to show the distribution of atoms in steel and find which distribution is better suited to give certain qualities. While the art is still in its infancy and it may be a number of years before sufficient data are collected, Dr. Lester expressed his opinion that results would ultimately be obtained that would insure a great improvement not only in steel castings but in other steels as well.

After Dr. Lester had concluded, a business meeting was called.

It was decided that the most important objective for the current year was to increase the membership, and several suggestions were made along this line. It was suggested that a membership committee be appointed to personally solicit new members, and it was moved and passed that this committee be appointed by the executive committee.

It was also suggested that it might be well to assign one prospective member to a solicitor and have him concentrate on him, rather than have several prospects assigned to him with consequent less time for solicitation per prospect.

Mr. Porter read letters from Cleveland and Rochester telling how they handled the membership question.

Mr. Learned suggested the formation of a union or association composed of all the local engineering societies, similar to that in Hartford and Providence, with a common headquarters. This suggestion met with the approval of those present, but was not discussed at length due to the lateness of the hour.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. **M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.**

NEW MEMBERS

ALDEN, H. L., (Jr-11) student, Case School of Applied Science; *mail* 2107 Adelbert Road, Cleveland.

ALLEN, R. M., (A-2), sales work, Allegheny Steel Co.; *mail* 4-134 General Motors Bldg., Detroit.

ANDERSON, GUNVALD, (M-12), toolmaker, Nice Ball Bearing Co.; *mail* 2716 North 16th St., Philadelphia.

ANDERSON, W. S., (M-2), chemical engineer and metallurgist, Boston Consolidated Gas Co., Boston; *mail* 9 Fairland St., Roxbury, Mass.

ATKINS, R. G., (M-2), metallurgical department, United Alloy Steel Corp.; *mail* 1424 12th St., Canton, Ohio.

BEAM, R. C., (Jr-1), student, *mail* 65 13th Ave., Columbus, Ohio.

BERG, OSCAR, (M-1), mechanical superintendent, Brown and Bigelow, St. Paul, Minn.

BENBOW, B. L., (M-1), manager, Cleveland Wire Division, National Lamp Works; *mail* 1770 East 45th St., Cleveland.

BIGGE, H. C., (M-11), superintendent electric furnace department, Bethlehem Steel Co.; *mail* 510 Third Ave., Bethlehem, Pa.

BINNS, H. S., (M-2), metallurgist, Cincinnati Milling Machine Co.; *mail* 4115 31st St., Oakley, Cincinnati, Ohio.

BIRCKELBAW, L. I., (M-2), plant engineering department, Hudson Motor Car Co.; *mail* 328 Smith Ave., Detroit.

BLAIR, W. R., (Jr-12), student, Massachusetts Institute of Technology, Cambridge; *mail* 123 Wyoming Ave., Melrose, Mass.

BOTT, JOSEPH, (M-11), engineer, Bastian Brothers; *mail* 207 Lux Street, Rochester, N. Y.

BOWDEN, C. A., (Jr-12), student, University of Pittsburgh; *mail* 2240 Cobden St., Pittsburgh.

BOYER, S. H., (A-2), salesman, Celite Products Co., 801 Keenan Bldg., Pittsburgh.

BRAEBURN ALLOY STEEL CORP., (S-2), Braeburn, Pa.

BRANTINGHAM, ALAN, (M-1), head of methods department, Emerson Brantingham Co., Rockford, Ill.

BREITHAUPT, J. C., (M-12), melter, Dodge Steel Co.; *mail* 1502 West 68th St., Philadelphia.

BRIESE, ALFRED, (M-2), plant superintendent, Wheeling Machine Products Co., Wheeling, W. Va.

BROOKER, JAMES, (M-1), metallurgist, Columbia Axle Co.; *mail* 10601 Dupont Ave., Cleveland.

BRUESHABER, M. W., (S-3), second vice-president, Goss Printing Press Co., Chicago.

BRYANT, L. W., (M-1), chief chemist, American Steel Foundries, East Chicago, Ind.

BURGOON, B., (M-2), general foreman, Railway Steel Spring Co., East St. Louis, Ill.

CARL, O. F., (A-2), special western sales representative, Crucible Steel Company of America, Chicago.

CARLSON, E. A., (M-12), foreman, steel treating, Kruse and Slattery Tool and Die Co.; *mail* 1510 Bradley Ave., Camden, N. J.

CHARLTON, KNIGHT, (M-12), special apprentice, Bucyrus Co.; *mail* 436 Hawthorne Ave., South Milwaukee.

CHIODO, R. W., (Jr-1), student, East Technical High School; *mail* 1438 East 176th St., Cleveland.

CHRISTENSEN, MAGNUS, (M-12), president, Bennett-Christensen Co., Cleveland.

CLARK, C. L., (Jr-12), student, University of Michigan; *mail* 207 South Ingalls St., Ann Arbor, Mich.

COATS, WILSON, (M-1), 731 West Genesee St., Lansing, Mich.

COFFIN, F. P., (M-1), research engineer, General Electric Co.; *mail* 1 Glenwood Blvd., Schenectady, N. Y.

COGHLIN, B. W., (M-11), president and general manager, J. Coghlin Co.; *mail* 2050 Ontario St., East Montreal, Canada.

COOK, N. E., (M-2), chemical technologist, National Road at Howards Station, Wheeling, W. Va.

CORBEAU, W. C., (M-12), melter, National Malleable and Steel Casting Co.; *mail* 759 Linn Drive N. E., Cleveland.

CRAIG, S. F., (M-1), assistant laboratory engineer, Hydro Electric Power Commission; *mail* 8 Stracham Ave., Toronto, Canada.

CRICK, L. H., JR., (M-1), assistant engineer, Bell Telephone Company of Pennsylvania; *mail* 6500 Darlington Road, Pittsburgh.

CURTIS, G. H., (M-11), tool grinder, North East Electric Co.; *mail* 35 Rowley St., Rochester, N. Y.

DENNISON, W. W., (M-12), inspector, Baldwin Locomotive Works; *mail* 612 North 55th St., Philadelphia.

DIERKER, A. H., (Jr-2), student, Ohio State University; *mail* 818 Gilbert St., Columbus, Ohio.

DODDS, G. C., (M-11), foreman, heat treating, American Swiss File and Tool Co.; *mail* 839 Anna St., Elizabeth, N. J.

DURKEE, W. B., (A-1), president, Wm. B. Durkee, 287 Atlantic Ave., Boston.

ECHLIN, E. C., (M-1), factory superintendent, Echlin, Schulin and Echlin; *mail* 799 Golden Gate Ave., San Francisco.

EDWARDS, ROBERT, (Jr-10), student, Case School of Applied Science; *mail* 1841 East 117th St., Cleveland.

EICKMEYER, A. H., (M-2), heat treater, Davis Boring Tool Co.; *mail* 2209 Angelica St., St. Louis.

EULBERG, WM. J., JR., (M-2), metallurgical assistant, Illinois Tool Works; *mail* 3301 North Troy St., Chicago.

FERGUSON, GORDON, (M-2), warehouse foreman, Braeburn Alloy Steel Corp.; Braeburn, Pa.; *mail* 1619 Kenneth Ave., Arnold, Pa.

FIELDING, R. G., (M-2), superintendent heat treating, Diamond Chain and Manufacturing Co.; *mail* 402 West 39th St., Indianapolis.

FINK, W. L., (Jr-2), student, University of Michigan; *mail* 1014 Cornwall Place, Ann Arbor, Mich.

FISHER, A. F., (M-1), factory manager, Robeson Rochester Corp., Perry, N. Y.

FISHER, M. B., (A-12), salesman, Leeds & Northrup Co., Chicago.

FITZGERALD, T. C., (M-1), special apprentice; *mail* 517 30th St., Rock Island, Illinois.

FLAGG, F. P., (M-1), chief chemist, Waltham Watch Co.; *mail* 20 Floyd St., Waltham, Mass.

FLAGLE, W. W., (M-12), engineer of tests, research department, National Malleable Co.; *mail* 671 East 107th St., Cleveland.

FOCKE, A. E., (Jr-12), student, Ohio State College; *mail* 48 Kelso Road, Columbus, Ohio.

FORD, H. D., (M-12), superintendent tractor heat treating department, Ford Motor Co.; *mail* 6323 Northfield Ave., Detroit.

FOX, W. C., (M-1), chief chemist and metallurgist, Mansfield Sheet and Tin Plate Co., Mansfield, Ohio.

FRANCE, E. A., (M-12), factory manufacturer and vice-president, France Packing Co.; *mail* 3124 Tyson St., Tacony, Philadelphia.

FREAR, C. L., (M-2), chemist and metallurgist, DeLaval Separator Co.; *mail* 12 Innis Ave., Poughkeepsie, N. Y.

FREEMAN, J. R., JR., (M-2), physicist, division of metallurgy, Bureau of Standards; *mail* 918 19th St., Washington, D. C.

FRIEDMAN, J. H., (M-2), superintendent, National Machinery Co., Tiffin, O.

GILBERT, C. E., (S-2), general manager and president, Dreses Machine Tool Co., Cincinnati, Ohio.

GOODAIRE, E. W., (M-12), Cleveland Frog and Crossing Co., Cleveland.

GORMAN, G. F., (M-1), metallurgist and superintendent heat treating, Canton Drop Forge and Manufacturing Co., Washington Blvd., Canton, Ohio.

GRAHAM, F. H., (M-2), engineer, Wm. Swindell Bros.; *mail* 404 Center St., Wilkinsburg, Pa.

GREEN, WALTER, (M-2), foreman hardener, S. W. Card Mfg. Co.; *mail* Pratt St., Mansfield, Mass.

HALE, GORDON, (M-12), W. S. Bidle Co., Cleveland.

HARTWELL, ARTHUR, JR., (Jr-12), student, University of Michigan, Ann Arbor, Mich.; *mail* 217 Brown St., Birmingham, Mich.

HAWK, HARRY, (M-2), heat treater, Bagshaw-Field, Ltd.; *mail* 5118 Westminster Ave., Philadelphia.

HECK, S. M., (M-1), metallurgical department, Carpenter Steel Co., Reading, Pennsylvania.

HENDERSON, C. M., (A-2), general manager, H. C. Macauley Foundry Co.; *mail* 5424 Golden Gate Ave., Oakland, Calif.

HERSCHMAN, H. K., (M-1), assistant scientist, Bureau of Standards, Washington, D. C.

HODGE, J. C., (M-12), chemist, Bennett-Christensen Co., Cleveland.

HOENER, E. A., (M-1), Firestone Products Co., Akron, Ohio.

HUTTON, F. B., (Jr-1), student, Ohio State University; *mail* 1927 Waldeck Ave., Columbus, Ohio.

HUTTON, T. S., (A-11), special representative, Warman Steel Casting Co.; *mail* 1704 Marin Ave., Berkeley, Calif.

IPSEN, C. M., (M-2), general foreman, Railway Steel Spring Co., Latrobe, Pa.

JEROME, J. H., (A-2), salesman, Kinite Co., 50 Church St., New York City.

JOHNSON, O. W., (M-11), toolmaker, North East Electric Co.; *mail* 3 Evangeline St., Rochester, N. Y.

JORGENSON, E. M., (M-1), secretary manager, Earl M. Jorgenson Co., 1004 Washington Bldg., Los Angeles, Calif.

JUSTICE, R. W., (A-1), salesman, E. F. Houghton & Co., Philadelphia; *mail* 800 Oakmont Ave., Steubenville, Ohio.

KELLER, O. V., (Jr-2), student, University of Michigan; *mail* 535 Packard, Ann Arbor, Mich.

KENLAN, C. H., (A-2), salesman, Colonial Steel Co.; *mail* 24 Leo Place, Newark, N. J.

KRIVOBOK, V. N., (M-2), research associate, Carnegie Institute of Technology, Pittsburgh.

LARSON, R. H., (S-12), power engineer salesman, Rockford Electric Co., Rockford, Ill.

LEA, R. C., (A-1), 303 W. P. Story Bldg., Los Angeles, Calif.

LEONARD, R. D., (S-1), vice president and general manager, Atlantic Refining Co., Philadelphia.

LIEN, ALFRED, (M-12), heat treater, Ingersoll Milling Machine Co.; *mail* 1428 Woodruff Ave., Rockford.

LLOYD, D. S., (Jr-2), student, University of Toronto; *mail* 80 St. George St., Toronto, Canada.

LUCAS, A. W., (A-2), salesman, Crucible Steel Company of America; *mail* 172 Washington St., Wallingford, Conn.

LUCAS, J. E., (Jr-1), student, Ohio State College; *mail* 62 Chittendon Street, Columbus, Ohio.

LYNN, SCOTT, (M-2), general manager, Sangamo Electric Company of Canada, Ltd.; *mail* 183 St. George St., Toronto, Canada.

MACTAGGART, DAVID, (M-3), assistant in metallurgical laboratory, Halcomb Steel Co.; *mail* 109 Onondaga Ave., Syracuse, N. Y.

MCCAMBRIDGE, J. E., (M-12), metallurgist, Navy Yard; *mail* 126 Lynn Blvd., Highland Park, Pa.

MCGARY, A. D., (M-1), chief chemist, York Metal and Alloys Co.; *mail* 12 South Queen St., York, Pa.

MEAKER, C. R., (M-1), foreman, Standard Safety Corp.; *mail* 1304 West Pico St., Los Angeles, Calif.

MEIER, FRED, (M-1), master mechanic and assistant superintendent, Sherwin Williams Co.; *mail* 8035 Blackstone Ave., Chicago.

MEISLER, J. C., (M-2), master mechanic, Curtis Publishing Co.; *mail* 31 East Holly Ave., Oaklyn, N. J.

MEKLER, W. A., (Jr-12), student, University of Pittsburgh, School of Mines, Pittsburgh.

MILNE, THEODORE, (Jr-11), student, Massachusetts Institute of Technology, Cambridge; *mail* 243 Chestnut Ave., Jamaica Plain, Mass.

MITCHELL, D. E., (M-12), metallurgical department, Dodge Bros.; *mail* 15086 Fielding Ave., Brightmoor, Detroit.

MOESSNER, G. D., (M-12), chemical engineer, Buckeye Steel Castings Co.; *mail* 407 Berkley Road, Columbus, Ohio.

MORGAN, F. T., (A-2), president, Morgan Steel Co.; *mail* 1232 Callowhill St., Philadelphia.

MULFORD, H., (M-12), superintendent, Interstate Drop Forge Co., Milwaukee.

NELSON, J. E., (M-12), industrial engineer, Merchants Heat and Light Co.; *mail* 623 North Riley Ave., Indianapolis, Ind.

NETTLETON, WM., (M-11), president, Nettleton Steel Co.; *mail* 1371 East 45th St., Cleveland.

NIELSON, L. G., (M-12), toolmaker, Delta File Works, Bridesburg, Philadelphia.

NILSON, CARL, (M-2), metallurgical department, Hudson Motor Car Co., Detroit.

NOWLAND, B., JR., (M-12), research department, Midvale Co., Nicetown; *mail* 7249 Limekiln Road, Germantown, Philadelphia, Pa.

OSBORNE, EDGAR, (M-1), metallurgist, Buick Motor Co.; *mail* 822 West Anne St., Flint, Mich.

OSLAND, C. R., (M-1), chief chemist, American Steel Foundries Co., East St. Louis, Mo.

PARKER, J. C., (S-2), Lefax, Inc., 9th and Sansom Sts., Philadelphia.

PEARSON, P. R., (M-1), metallurgist, Arthur D. Little, Inc., Cambridge, Mass.

PEYTON, HARRY, (M-2), assistant superintendent, spring department, Railway Steel Spring Co., Chicago Heights, Ill.

PIHLMAN, A. A., (M-2), industrial gas engineer, Consumers Power Co., Pontiac, Mich.

PILLIOD, R. V., (M-2), assistant general manager, Pilliod Co., Swanton, Ohio.

POBANZ, W. A., (M-2), heat treater, John Deere Co.; *mail* Box 37, Colona, Ill.

POISTER, R. S., (M-1), electric furnace foreman, United Alloy Steel Corp.; *mail* 1130 Piedmont Ave., N. E., Canton, Ohio.

PROCTOR, E. M., (Jr-2), student, Massachusetts Institute of Technology; *mail* 235 Clifton St., Walden, Mass.

PUTNEY, C. M., (M-12), foreman fence department, Horace T. Potts Co.; *mail* 215 East Tabor Road, Olney, Philadelphia.

RAYMOND, S. E., (M-1), order department, Otis Steel Co.; *mail* 3826 Euclid Ave., Cleveland.

REDLIN, E. E., (A-1), salesman, E. F. Houghton & Co.; *mail* 3312 East Scarborough Road, Cleveland Heights, Ohio.

REMMERS, W. E., (M-1), instructor, iron and steel, Washington University; *mail* 1101 Dover Place, St. Louis, Mo.

RIBAR, EDWARD, (M-1), R. F. D. No. 5, Fremont, Ohio.

RIDGELY, F. R., (M-11), Barber Colman Co.; *mail* 39 Clay Ave., Rochester, New York.

ROBERTS, THOMAS, (M-2), chief chemist and metallographist, Brymbo Steel Co., Ltd.; *mail* 17 Earle St., Wrexham, North Wales.

SCHAEFER, R. E., (Jr-2), student, University of Michigan; *mail* 535 Packard, Ann Arbor, Mich.

SCHEUCH, W. A., (M-12), metallurgist, development, Western Electric Co.; *mail* 651 North Mayfield Ave., Chicago.

SCHLUMPF, R. W., (M-1), metallurgist, Hughes Tool Co., Houston, Texas.

SCHMIDT, W. G., (M-12), tool room and heat treating foreman, Brown Instrument Co.; *mail* 4724 D St., Philadelphia.

SCHUBERT, F. R., (S-1), works manager, Strom Ball Bearing Mfg. Co., Chicago.

SCOTT, L. K., (A-2), vice president and general sales manager, Latrobe Electric Steel Co., First National Bank Bldg., Pittsburgh.

SEARS, RICHARD, (Jr-10), student, Case School of Applied Science; *mail* 2107 Adelbert Road, Cleveland.

SHIPMAN, G. E., JR., (M-2), metallurgical assistant, Illinois Tool Works; *mail* Kenilworth, Ill.

SLOCUM, L., (A-1), sales manager, Wetherell Bros. Steel Co., Cambridge, Mass.

SMITH, W. E., (M-2), foreman, John Deere & Co.; *mail* 1327 17th St., Rock Island, Ill.

STEELE, W. R., (M-12), superintendent, Lamb Machine Co., Hoquiam, Wash.

STOTZ, N. I., (M-1), metallurgical engineer, Braeburn Alloy Steel Corp., Braeburn, Pa.

TAYLOR, J. F., (A-2), salesman, Crucible Steel Company of America, Chicago.

TAYLOR, P. H., (A-12), salesman, Leeds & Northrup, Chicago.

TELFER, WM., (M-2), instructor in forge shop, University of Michigan; *mail* Washtenaw Road, Ann Arbor, Mich.

THOMAS, H. C., (M-2), president, Henry Charles Thomas, 337 King St., W., Toronto, Canada.

THOMSON, ROBT., (M-1), metallurgical department, Standard Oil Co., Elizabeth, N. J.

THORNE, R. W., (A-2), salesman, Colonial Steel Co.; *mail* 292 West Walnut St., East Orange, N. J.

TILLEY, MILTON, (M-12), metallurgist, National Malleable and Steel Castings Co., Cleveland.

TOMKO, MICHAEL, (M-1), metallurgist, Columbia Axle Co.; *mail* 11515 Shadeland Ave., Cleveland.

TOMPKINS, C. S., (S-1), Crescent Washing Machine Co., New Rochelle, N. Y.

UPDIKE, D. F., (M-1), assistant professor of metallurgy, Missouri School of Mines; *mail* Box 248, Rolla, Mo.

VAN DYKE, FRED, (M-12), heat treating foreman, Ford Motor Car Co.; *mail* 2281 Cortland Ave., Detroit.

VOSE, W. C., (Jr-2), student, Massachusetts Institute of Technology; *mail* 28 Clifton Ave., Marblehead, Mass.

WALCHER, E., (M-2), works manager, American Steel Foundries, Granite City, Illinois.

WALLIS, C. T., (M-10), engineer, North East Electric Co.; *mail* 119 Filmore St., Rochester, N. Y.

WATKINS, M. MARK, (A-12), Chicago district manager, Brown Instrument Co., Chicago.

WEAVER, F. L., (M-2), chemist and steel treater, American Radiator Co.; *mail* 341 Massachusetts Ave., Buffalo, N. Y.

WESTENBERGER, CHAS., (M-12), heat treater, Atlantic Refining Co.; *mail* 2514 South 17th St., Philadelphia.

WIGHT, F. L., (A-1), sales agent, U. S. Steel Products Co., San Francisco.

WILBUR, M. D., (A-2), salesman, Latrobe Electric Steel Co.; *mail* 113 Jefferson Ave., Rochester, N. Y.

WILDNER, E. L., (Jr-12), student, Massachusetts Institute of Technology, Cambridge, Mass.; *mail* 33 Bay State Road, Boston.

WILHELM, E. W., (M-2), superintendent, R. W. Wilhelm Die Tool Machine Co.; *mail* 5117 Center St., Pittsburgh.

WILHELM, R. W., (M-2), president, R. W. Wilhelm Die Tool Machine Co.; *mail* 1210 Wightman St., Pittsburgh.

WILSON, DON, (M-12), electric furnace melter, Kinite Co.; *mail* 708, Y. M. C. A., Milwaukee.

WILSON, R. B., (Jr-2), 7021 Vandyke St., Tacony, Philadelphia.

WOHLGEMUTH, G. F., (M-11), associate metallurgist, U. S. Naval Experimental Station; *mail* 134 Prince George St., Annapolis, Md.

YATES MACHINE CO., P. B., (S-12), Rockford, Ill.

ZIMA, A. G., (Jr-3), student, University of Minnesota; *mail* 2833 Grand Ave., South Minneapolis, Minn.

Items of Interest

THE growth of the research and development work of the Bell System has led to the formation of Bell Telephone Laboratories, incorporated, organized on January 1, 1925, for the purpose of carrying on development and research activities in the communication and allied fields.

This new company, which is jointly owned by the American Telephone and Telegraph Company and the Western Electric Company, incorporated, has taken over the personnel, buildings and equipment of the research laboratories of these two companies which were formerly operated as the Engineering Department of the Western Electric Company.

Extensions of laboratory facilities for the scientists and engineers of the new corporation are already under way. Laboratory space in the form of a new building covering almost a quarter of a city block will be added to the 400,000 square feet at present in service in the group of buildings at 463 West Street, New York City. At the date of incorporation, the personnel numbered approximately 3,600, of whom about 2,000 are members of the technical staff, made up of engineers, physicists, chemists, metallurgists, and experts in various fields of technical endeavor.

The chairman of the board of directors of the Bell Telephone Laboratories, incorporated, is General J. J. Carty, vice president of the American Telephone and Telegraph Company.

Other members of the Board are: Dr. F. B. Jewett, formerly vice president of the Western Electric Company, who is president of the new corporation, and also recently elected vice president of the American Telephone and Telegraph Company; W. S. Gifford, executive vice president of the American Telephone and Telegraph Company; C. G. DuBois, president, and J. L. Kilpatrick, vice president of the Western Electric Company, and J. B. Odell, assistant to the president of the Western Electric Company.

The operations of the Bell Telephone Laboratories, incorporated, are under the direction of E. B. Craft, executive vice president, who was formerly chief engineer of the Western Electric Company.

In the functional division of the research, development and engineering work of the laboratories, physical and chemical research is organized under Dr. H. D. Arnold, director of research; development of apparatus under J. J. Lyng, apparatus development engineer, and development of communication systems under A. F. Dixon, systems development engineer, all formerly concerned with similar activities in the engineering department of the Western Electric Company. Dr. R. L. Jones, inspection manager, continues his former responsibilities in engineering inspection, and S. P. Grace, commercial development engineer, those of commercial development.

The patent work of the laboratories is organized under J. G. Roberts,

general patent attorney, formerly assistant general patent attorney of the Western Electric Company.

The corporate and commercial relations of the laboratories are under the direction of vice president E. P. Clifford, who was formerly commercial manager of the engineering department of the Western Electric Company. John Mills continues as personnel director, responsible for personnel activities, and educational and college relations.

The formation of Bell Telephone Laboratories, incorporated, provides an individual organization, the whole activities of which may be more efficiently devoted to the furtherance of research, development and engineering investigations along the line in which the parent companies have already made such remarkable progress. Its formation is an indication of the estimate which these companies place upon the importance of properly organized research and is a promise of continuous service to the public, to the communication art and to the progress of science.

Eight Cleveland men are among two hundred engineers appointed as local representatives of the Engineering Foundation with national headquarters at New York. The Cleveland group includes:

James H. Herron, president of the James H. Herron Company, 1360 West 3rd Street; Zay Jeffries, research engineer of the Aluminum Company of America; A. J. Porskievies, The Electric Controller & Manufacturing Company, 2700 East 79th Street; Arthur V. Ruggles, engineer of construction and surveys, Division of Water, City Hall; Harry E. Scott, assistant chief engineer of the Brown Hoisting Machinery Company, 4403 St. Clair Avenue; Frank L. Sessions, mechanical and electrical expert, Rockefeller Building; Fred H. Vose, professor of mechanical engineering, Case School of Applied Science; Wilbur J. Watson, president of The Watson Company, 4614 Prospect Avenue.

The Cleveland engineers, with the others named, will, it was stated, work with the Foundation Board in prosecuting a nation-wide plant of research "for the furtherance of research in science and in engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind." The appointees represent industry, education and the public service.

Governor James G. Scrugham heads a group appointed from Nevada, which includes members of the faculty of the State University, the Macay School of Mines, and the mining industry. President C. H. Clapp of the State University of Montana is one of a group from that state which includes officials of the Anaconda Copper Mining Company and other industries. Practically all of the leading universities of the country are represented.

The Foundation's work will be carried on with the $500,000 endowment provided by Ambrose Swasey of Cleveland, reinforced by a recent bequest of $50,000 from the estate of Henry R. Towne. A group of prominent engineers in New York and other centers are charged with the immediate direction of the Foundation's affairs.

Co-operation with the National Research Council has been carried on by

(*Continued on Page 34 Advertising Section*)

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

RGE SHOP FOREMAN desires position with pos advancement. Experienced in all kinds of ham- forgings, tool dressing, hardening, and heat ting. Also competent of designing dies, tools, res and furnaces for economical productions. ress 2-10.

TALLURGICAL CHEMIST—For past 5 years and present superintendent of plant comprising forg- machine shop, heat treatment, grinding and shing departments. Educated as metallurgical mist. 40 years of age. Clean record. Good rences. Wishes to change for good reasons, erably out of the shop. Details upon request. ress 2-15.

TALLURGIST AND METALLOGRAPHIST—Uni- sity graduate with 3 years' of practical experi- e in metallurgical department of large steel plant. uble of conducting thorough investigations on ous and non-ferrous metals. Has thorough tech- l and practical training in metallography of iron steel. Experienced in the heat-treatment of ight carbon and alloy steels. Location in middle t preferred. Address 2-20.

ISTANT METALLURGIST desires position. Age college graduate, with 2¾ years' experience research work, ferrous and non-ferrous. At ent employed and can give excellent references. ation unimportant. Address 3-5.

TALLURGIST, CHEMIST with 14 years' experi- e in the metallography, heat-treating, physical ing and manufacture of the non-ferrous alloys, res position. Experience also embraces the ous industry of steels, alloy steels, and the o-alloys and compounds of vanadium, tungsten molybdenum. Address 3-10.

EMIST AND METALLURGICAL ENGINEER h 6 years' practical experience in mill, factory, ratory and executive capacity, desires to make w connection. Age 29. Address 3-15.

POSITIONS WANTED

ASSISTANT METALLURGIST desires position. 10 years' practical experience in heat-treating department and laboratory of several well known concerns. Boston district preferred. Married. Address 3-10.

METALLURGIST, CHEMIST with 12 years' experience in chemical, physical, microscopical laboratory work, as well as heat treating, forging and melting, desires position. Qualified to take charge. Cleveland district preferred. Address 3-35.

POSITIONS OPEN

SALES ENGINEER WANTED. If you are looking for an opportunity for rapid advancement and an excellent chance to assume worth while responsibility, with compensation according to your sales ability, describe your experiences fully so an appointment can be made for personal interview. You must have had sales and engineering experience, and should know something about instruments, gauges, and CO_2 recorders. Address 3-20.

PYROMETER SERVICE ENGINEER WANTED with experience in maintenance and repairing of pyrometers. Prefer men with at least 3 years' technical experience, having had some experience in a pyrometer manufacturing plant. Give full details as to experience in first letter. Will be required to travel about half time. Address 3-25.

WANTED RECENT GRADUATE OF METALLURGY for metallography laboratory modern laboratory and equipment. Salary $125.00 per month. Please include references and training in first letter. Location Pittsburgh Address 3-40.

FOR SALE

FOR SALE—LEITZ METALLOGRAPHIC MICRO-METALLOGRAPHIC EQUIPMENT. Complete. Guaranteed perfect. Attractive price. Address 2-5.

FOR SALE: One Eaton electric drawing furnace complete with automatic control panel and thermometer. Guaranteed to be in A-1 condition. All new elements. Cost $1,000.00 new, will sell at 50c on the dollar and guarantee. Address Claud S. Gordon Co., 708 West Madison Street, Chicago.

the Engineering Foundation, according to the announcement. With research committees of the Founder Societies of Civil, Mining and Metallurgical, Mechanical and Electrical Engineers, the Foundation is co-operating in investigations of concrete and reinforced concrete arches, steel columns for buildings and bridges, mining methods, rock-drill steels, properties of steam, bearing metals, lubrication, and strength of gears.

Besides the Foundation's appropriations to aid research, totaling $15,000, contributions from industries and other sources aggregate more than $100,000. Personnel research in industry, commerce, education and government will be furthered during the coming year through the Personnel Research Federation.

"Efforts are being made to increase the Foundation's endowment so that larger work may be done," the announcement said. The presidents and other representatives of the Founder Societies are aiding.

"Many useful projects of the Societies and the Foundation await larger resources. Nevertheless, by using its funds to inspire and aid and supplement, the Foundation has accomplished co-operatively noteworthy results.

"As it approaches the end of its first decade, the Foundation looks forward to a future of greater service with the united support of the engineering profession, of the industries, and of individuals who have built fortunes upon engineering."

Representatives announced are affiliated with numerous national organizations in addition to engineering societies, the list including the American Chemical Society, the American Associaton for the Advancement of Science, the Iron and Steel Institute, Society for Promotion of Engineering Education, American Society for Steel Treating, and The American Meteorological Society.

The United States Civil Service Commission announces an open competitive examination for the positions of: Junior Laboratory Mechanic (Instrument Maker), $1,320; Assistant Laboratory Mechanic (Instrument Maker), $1,500; Laboratory Mechanic (Instrument Maker), $1,680; Senior Laboratory Mechanic (Instrument Maker), $1,860.

Receipt of applications for these positions will close March 10. The examinations are to fill vacancies in the Bureau of Standards, Department of Commerce, at the entrance salaries shown above. Advancement in pay may be made without change in assignment up to $1,680 a year for junior laboratory mechanic, up to $1,860 a year for assistant laboratory mechanic, up to $2,040 a year for laboratory mechanic, and up to $2,400 a year for senior laboratory mechanic.

The duties of the positions are to design, construct, and repair scientific and technical instruments and apparatus of high precision. The relative responsibility of the work involved will vary according to the grade of the position, the higher-salaried grades embracing duties of difficulty and responsibility.

A similar open competitive examination will be held for the position of Assistant Mechanical Engineer (Cryogenic).

Receipt of applications for assistant mechanical engineer (cryogenic)

S. M. Co. Brinell Machine

This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

The Standard Machine Adopted by

American Can Co.
American Machine & Mfg. Co.
E. C. Atkins & Co.
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Carbon Steel Co.
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Chicago Pneumatic Tool Co.
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Curtiss Aeroplane & Motor Co.
Dayton Engineering Laboratories
Dominion Steel & Foundry Co., Ltd.
Eagle Pitcher Lead Co.
Firth-Sterling Steel Co.
Henry Ford & Son, Inc.
General Electric Co.
Hughes Tool Co.
Latrobe Electric Steel Co.
Lincoln Motor Co.
Maxwell Motor Co.
McMyler Interstate Co.
Nash Motors Co.
Oliver Chilled Plow Works
Parish & Pool Co.
Piston Ring Co.
Pittsburgh Testing Laboratory
Pollak Steel Co.
Premier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY
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will close March 10. The examination is to fill a vacancy in the Bureau of Mines, Department of the Interior, for duty at Lincoln, Nebraska, at an entrance salary of $2,100 a year, and vacancies in positions requiring similar qualifications.

The duties of the position consist of the operation of experimental liquefaction plants involving the care and operation of high pressure compressor equipment, the calibration of thermocouples and taking data involving the reading of electric temperature instruments, pressure gauges, manometers, etc., which may be included as part of the experimental equipment at such experimental plants.

Competitors will not be required to report for examination at any place, but will be rated on their education, experience, and fitness; and writings to be filed with the application.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil-service examiners at the post office or custom house in any city.

J. M. Watson, metallurgical engineer of the Hupp Motor Car Corporation, Detroit, has been appointed as chairman of the Iron and Steel Division of the

J. M. WATSON

S. A. E., filling the vacancy created by the resignation of F. P. Gilligan of Hartford.

The S. A. E. have made a very fine selection in Mr. Watson, inasmuch as his broad experience in iron and steel, as well as his executive ability, will

A Section of Our Chemical Labratory

IN submitting SIMONDS STEELS to the trade, we endeavor at all times to maintain the unexcelled quality that has made our saw products the standard throughout the world for almost a century.

We have specialized in the manufacture of a limited number of steels with the idea of developing each to the highest degree of perfection known to the art of steel making.

As manufacturers of crucible tool steel our experience covers a period of twenty years. In the production of electric alloy and special steels, we are one of the pioneers, having installed our first electric melting furnace in 1910, two years after the process was introduced into this country.

Our chemical, physical testing, and metallurgical laboratories are constantly testing our products,—at every stage of manufacture from the cast ingot to the finished product.

Our research department is also available for the study of your steel problems and the development of a steel that will answer all your requirements.

SIMONDS SAW AND STEEL COMPANY

Steel Mills — Lockport, N. Y.

BARS SHEETS BILLETS

produce a fine combination for the accomplishment of activity in the Iron and Steel Division.

Mr. Watson is a member of the national Finance Committee of the A. S. S. T., and past chairman of the Detroit chapter of the A. S. S. T.

To encourage the study of economics two prizes of $1000 and $500 are offered by Alvan T. Simonds, president of the Simonds Saw and Steel Company of Fitchburg, Massachusetts, for the best two essays on the following subject: "Your Prosperity and Mine."

The contest is open to all residents of the United States and Canada. It is hoped that it will especially appeal to business executives, assistants to business executives and students of business and commerce.

Contestants, who are not well versed in economics, are advised to study elementary works, dealing with fundamentals, and to read articles on economic subjects in newspapers and magazines. The essays may be entirely original or may be based, in whole or in part, on books or articles. If the latter plan is followed, references to the books and articles should be given in footnotes.

The essays must be at least 2500 words in length and should not exceed 3500 words. *They must be typewritten and on one side of the paper only.*

The prize winning essays, upon payment of the prizes, will become the property of Alvan T. Simonds.

The judges will be announced later. They will be selected from experts in economics, business, and related activities. Their decision must be accepted by all concerned as final.

The essays must reach the Contest Editor, Simonds Saw and Steel Company, 470 Main Street, Fitchburg, Massachusetts, on or before December 31, 1925.

The American Gas Association, with headquarters at 342 Madison Ave., New York City, has just published a 75-page treatise on "Combustion." This publication is the second of a series on the industrial application of gas and is a reference on the theory and practice of the principles of combustion. The price of this publication to members of the American Gas Association and other educational societies is $1.50; to non-members, $3.00.

Prof. Frederick Crabtree, head of the department of mining and metallurgical engineering, Carnegie Institute of Techonology, Pittsburgh, since 1906, died at St. Petersburg, Fla., February 14. Professor Crabtree was born in Bramley, York, England, February 1, 1867. He attended Massachusetts Institute of Technology, graduating with the degree of bachelor of science in chemistry in 1889. He was chemist with the Illinois Steel Co. in 1889 and with the National Tube Co. from 1890 to 1900. He was superintendent of the Western Steel Co., 1900 to 1901, and later superintendent of the blast furnaces with the Colorado Fuel and Iron Co. until 1904. From 1904 to 1906 he was professor of mining and metallurgy at the Colorado College, Colorado Springs, Colo. Leaving that position he went to Pittsburgh and joined the staff of Carnegie Institute of Technology. Professor Crabtree was a member

of the American Institute of Mining and Metallurgical Engineers; American Iron and Steel Institute; American Electro-chemical Society; Engineers' Society of Western Pennsylvania; British Iron and Steel Institute; American Society for Steel Treating.

Samuel Arnold 3rd, formerly chief engineer, Tate Jones and Company, and prior to his connection with them, assistant electrical engineer with the American Bridge Company, is now the representative of the American Bridge Company in the sale of Heroult electric steel melting furnaces, and in addition to this is doing consulting work on all types of industrial furnaces. Mr. Arnold's address is 1306 Fulton Building, Pittsburgh.

Martin H. Schmid, metallurgical engineer of the United Alloy Steel Corporation, Canton, Ohio, has been appointed assistant general manager of sales of the alloy division of the company, effective December 1. He was graduated from Lehigh University in 1907 with the degree of mechanical engineer, and for two years was engaged in power plant work.

Dr. B. D. Saklatwalla has been appointed vice president of the Vanadium Corporaion and of the United States Ferro Alloys Corporation. He was formerly general superintendent of the Bridgeville plant of the Vanadium Corporation.

Edward T. Moore has opened an office at 500 Cahill Building, Syracuse, N. Y., for the general practice of consulting engineering and the manufacture of the Moore electric power regulator. He will specialize in industrial plant problems and in electric furnace installations with which his regulator is closely allied. Mr. Moore was formerly chief engineer of the Halcomb Steel Co. at Syracuse and consulting engineer for the Crucible Steel Co. of America.

Arthur T. Clarage, son of the late E. T. Clarage, who was founder and first president of the Columbia Tool Steel Company, Chicago Heights, Ill., has been elected president of the company succeeding A. R. Waters, who retired recently. Mr. Waters was also one of the founders and has been active as general manager and president since the company's inception in 1904. Arthur T. Clarage has held many positions with the company and has been general manager and director since 1920. He needs no introduction, being already known to the industry and trade through his work in charge of operation and sales activities. He has been closely identified with the progress of the company in recent years, both in the operation and sales department. As an operator, he is known for his original work on the application of the electric furnace for annealing tool steel. He has also done a great deal with the elimination of spoilage problem, casting practice, raw material selection, etc. In maintenance of properties and general manufacturing policy he has been no small factor.

Mr. Clarage received his education in Chicago Technical Schools, coming with the company shortly after graduation. He is given charge as he completes his eleventh year with the company.

Not many years ago there were few uses for titanium minerals and products, but since 1900 the use of ferroalloys containing titanium has decidedly increased and a considerable number of patents relating to the production of such alloys have been issued, states J. W. Marden in Bulletin 212, recently issued by the Department of the Interior, through the Bureau of Mines. This increase has resulted from the general recognition of the efficiency of titanium as a purifying agent in the manufacture of steel. Metallic titanium has properties that restrict its use. It is white, but cannot readily be forged; it burns in oxygen to the oxide, and reacts directly with nitrogen.

Variable quantities of titanium occur in granite, gneiss, mica slate, syenite rocks, and sometimes in granular limestone and dolomite, as well as in magnetite, hematite, monazite, zirconium ores, and auriferous sands. Ilmenite is often present in deposits of magnetite.

The most important use of titanium has been in making the alloy, ferrotitanium, which is employed chiefly as a deoxidizer of iron and steel. Paints for protective coatings on iron and steel are made by mixing 10 to 15 per cent asphalt with rutile and thinning with turpentine. Titanium compounds are also of value in the dyeing industry; alkali titanium salts of organic acids, such as potassium titanium oxalate, are used as mordants and under some conditions give better results than aluminum salts. Titanous chloride or sulphate is used for bleaching silk and wool and titanium dioxide has been used as a catalytic agent in the esterfication of acetic acid. The use of titanium dioxide as a pigment in ceramic glazes probably consumes much of the oxide.

Methods of analysis for titanium must be general enough to apply to the many sets of conditions that may be encountered in (1) ores such as magnetite, hematite, rutile, ilmenite, granitic rocks, auriferous sands, clays, etc.; (2) furnace slags; and (3) ferroalloys which may contain many other elements than iron and titanium. Most of these compounds are insoluble in acids, and there seems to be much divergence of opinion as to their best fusion mixture for getting the substance into solution. Technical journals have recently given new methods for analyzing titanium in the presence of other substances, such as the methylene-blue titration for titanium in the presence of iron and fluorides, which does not seem to have found its way into many text books.

At present there are about 12 methods for the separation and estimation of titanium. The Bureau of Mines believed that it would render the industries a service by collecting, abstracting and discussing these methods, and calling attention to those that give rapid, accurate results, thus aiding the analyst who does not have time to review current literature carefully or to test new methods for himself. At present, methods are in demand for the determination of titanium in the presence of other elements without long and tedious separations. Methods of analysis for titanium, which have been thoroughly tested by the Bureau of Mines, are outlined in Bulletin 212, "Analytical Methods for Certain Metals," which may be obtained from the Superintendent of Documents, Washington, D. C., at a price of 40 cents.